Technological Breakthroughs and Productivity Growth

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To Josefin

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Stockholm, April 2006
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Part I

Introduction and Summary of Thesis

1. Introduction

> "Taking the population of the world at any number, a thousand millions, for instance, the human species would increase in the ratio of -- 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, etc. and subsistence as – 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, etc. In two centuries and a quarter, the population would be to the means of subsistence as 512 to 10: in three centuries as 4096 to 13, and in two thousand years the difference would be almost incalculable, though the produce in that time would have increased to an immense extent." (Malthus, 1798, chapter 2, paragraph 17)

When Thomas Malthus more than 200 years ago argued that population increases geometrically and supply can only increase arithmetically, he had no idea that history would prove him wrong, at least so far. What Malthus failed to consider in his theoretical argumentation was the development of agricultural technology and thereby the growth in productivity. The technological developments over the last centuries have substantially increased productivity and thereby affected welfare in the industrialized world. According to Hulten (2001), GDP per capita increased from approximately $700 in the 1860s to $27000 in the 1990s. The economic development has not always been smooth, but one of the driving forces behind the economic development over a longer time period has been the increase in productivity.

Productivity is a measure of how efficiently resources are used to produce goods and services. By producing in a more efficient way, it is possible to use the resources that are released in other production processes or increase the volume produced in existing processes, thereby increasing the growth of the total economy. Therefore, productivity growth is crucial for a country's welfare and standard of living. Hence, if an economic system can create high productivity growth rates, there will be substantial growth in that particular economy, since factor resources are being released and can be used in other sectors of the economy. So far, compared to other systems, the capitalist system has been the most successful in promoting high productivity growth over a long time period (Baumol 2002).

Most economists agree that innovations based on new technology are one of the driving forces of productivity growth. Nevertheless, it is not certain that a productivity-enhancing technology leads to increased productivity. One example is medieval China where several inventions such as paper, printing and the bill of exchange were made. However, the Chinese were not able to use their inventions in productive ways (Baumol 1993). One of the reasons was that when the sovereign was in financial difficulties, confiscation of property was used. The Chinese example illustrates that institutional structures and organizational change are also crucial for realizing productivity gains from new technology. Moreover, education, entrepreneurship and R&D investments have also been emphasized as important factors for productivity growth (Schumpeter 1966; Nelson 1959; Griliches 1988; Henrekson 1996; Henrekson & Rosenberg 2001).

Understanding exactly how different factors influence productivity growth is highly complex and beyond the scope of this dissertation. Instead, this dissertation investigates productivity growth following major technological breakthroughs. The primary focus is on the productivity growth following electrification and the information and communication technology (ICT) revolution, but some evidence is also presented for the steam engine revolution in the eighteenth and nineteenth centuries.

To understand the impact of major technological breakthroughs, it is crucial that productivity is measured correctly (Griliches 1988). Measuring productivity in industries producing homogenous products is straightforward. However, for industries with rapidly changing technology it is a different matter. The essential difficulty is to separate the price change of the products from the change in quality (Gordon & Griliches 1997). A number of methods have been developed to improve these measurement problems (see Breshnahan & Gordon 1997). Some of these methods, such as hedonic price indexes, have been used to measure productivity following the ICT revolution, but the impact of using these methods during earlier technological breakthroughs has not been sufficiently evaluated. Thus, this dissertation also investigates the impact of different measurement methods, such as hedonic price indexes, on productivity growth following major technological breakthroughs.

2. What is a technological breakthrough?

There are a number of different theoretical concepts that can be used to analyze and define major technological breakthroughs. This section summarizes and compares three of these concepts. This thesis has no intention of developing any new theory of technological breakthroughs. The intention is instead to show that if several different theoretical concepts are used, it is possible to distinguish a few major technological breakthroughs that have had an important impact on productivity growth for decades.

Three theoretical concepts are used: Development blocks, Techno-Economic Paradigms (TEP) and General Purpose Technologies (GPT). The least known is the development block-concept, developed by the Swedish economist Erik Dahmén in an effort to integrate the ideas of Schumpeter into a theory where innovations are crucial for growth (Dahmén 1950; 1988). The other two theories, TEP and GPT, are widely referred to in the literature, though surprisingly seldom compared.

2.1 Development Blocks

Schumpeter (1939) argued that new products and technologies, giving rise to "gales of creative destruction", would have a large impact on the economy for several decades. Influenced by Schumpeter, the Swedish economist Erik Dahmén developed the Schumpeterian framework with the concept of complementarities and development blocks (Dahmén 1950; 1988).

According to Dahmén, the diffusion of an innovation requires the realization of one or more specific complementary stages. During a complementary stage, a new innovation changes the need for knowledge, machinery, inputs, distribution, behavior etc., which results in adjustment problems that are specific for each innovation. However, if these problems are solved, the new innovation will result in increased growth. Thus, a development block is defined as a "sequence of complementarities which by way of a series of structural tensions i.e. disequilibria, may result in a balanced situation" (Dahmén 1988, p. 5).

According to Dahmén (1991), the construction of a railway network may be seen as an example of a development block, but also the electrification of a railway network as well as the exploitation of geographic areas with respect to industry, agriculture, and communications. These development blocks cannot be completed in one step and as long as they have not been completed, there remains a certain structural tension. Thus, it takes a prolonged period of time for a development block to be completed.

2.2 Techno-Economic Paradigm (TEP)

Another framework closely linked to the ideas of Schumpeter (1939) is the concept of Techno-Economic Paradigm (TEP) (Dosi 1982; Perez 1983; Freeman & Soete 1987). One of the major characteristics of the TEP framework is that it clearly distinguishes between incremental and radical innovations.

Incremental innovations occur more or less continuously, but at a varying rate across industries and time periods. The combined effects of incremental innovations are very important for productivity growth. However, they do not result in any dramatic increases in productivity growth. According to Freeman (1987), the effects of incremental innovations are apparent in the steady growth of productivity. Radical innovations are discontinuous events of importance for the growth of new markets. However, over a period of decades, the economic impact of radical innovations is quite small, unless a whole cluster of radical innovations result in entirely new industries. These clusters of innovations form a TEP.

According to Perez (1983), the establishment of a TEP is based on the introduction of a cluster of constellations of interrelated innovations, both technical and managerial, which lead to the attainment of a level of total productivity, clearly superior to what was normal with the previous TEP. Thus, a TEP is a systematic relationship among products, processes, organizations and institutions coordinating economic activity (Freeman 1987).

Changes of TEPs are pervasive changes in technology, affecting many branches of the economy and giving rise to entirely new sectors. One characteristic of this type of technical change is that it affects the input cost structure and the conditions of production and distribution for almost every sector of the economy.

2.3 General Purpose Technology (GPT)

The third theoretical framework is the General Purpose Technology (GPT) concept, introduced by Bresnahan and Trajtenberg (1995). They argue that whole eras of technical progress are driven by a few GPTs, characterized by pervasiveness, inherent potential for technical improvements and innovational complementarities. Pervasiveness implies that a GPT is used in many downstream sectors since it provides a generic function, such as rotary motion. The GPT also undergoes continuous improvements resulting in increased efficiency in the GPT over time. Finally, innovational complementarities imply that the productivity of R&D in the downstream sectors increases as a consequence of innovation in the GPT.

According to Helpman and Trajtenberg (1998), the characteristics of GPTs provide a mechanism so that the GPTs act as “engines of growth”. The consequences of improving the GPT are reduced costs in the downstream application sectors, the development of improved downstream products and increased adoption of the GPT in downstream sectors (Lipsey *et al.* 1998). This leads to more innovation in the GPT, which further improves the GPT. Thus, GPTs are believed to play a decisive role for long-term productivity development as the new technology is diffused throughout different sectors of the economy (Helpman & Trajtenberg 1998).

2.4 Comparing different approaches to technological breakthroughs

One similarity between all three theoretical concepts of technological breakthroughs is that they all put innovation at the center of the growth process. In this way, they are all based on Schumpeter’s (1939) ideas that innovations are crucial for economic growth. Moreover, all theories recognize that it takes a considerable amount of time before innovations have a large impact on growth and they also find that innovations may often give rise to totally new industries.

Although there are some similarities between the three theoretical concepts, there are also a number of differences. Dahmén (1950) was one of the first to develop the Schumpeterian ideas and thereby provided a new way of thinking about the diffusion of new technology and the process of growth. However, in contrast to the TEP and GPT theories, the development block theory is not very specific about how the process of innovation will result in productivity growth. Dahmén (1988) concludes that if certain adjustment problems are solved, new innovations will result in increased growth. However, he does not explain in what way new innovations lead to increased productivity growth. Thus, in the Dahménian framework, the way innovation affects productivity is a black box.

The TEP and GPT literature is more specific about the link between major innovations and productivity growth. According to Freeman (1987), it is through the input cost structure and the conditions of production and distribution that major innovations affect productivity growth. Lipsey *et al.* (1998) emphasize that GPTs results in increased productivity through reduced costs and improved products in the downstream application sectors. Hence, the TEP and GPT frameworks are very similar in their view on how innovations affect productivity growth.

While the development block and TEP concepts are closely related to a historical context, the GPT framework stems from a more neoclassical approach. In Helpman (1998), the GPT framework is variously characterized in terms of inter-industry linkages, R&D investments and coordination problems. Moreover, the GPT framework is often applied to perfect-foresight, general equilibrium models that seem to deny the premise of historical technological trajectories (David & Wright 2003).

The neoclassical approach allows the definition of GPTs to be more precise than the other theories. However, since a GPT is defined according to a clear set of *ex post* criteria, the ability to identify a GPT is also time dependent. As noted by Lipsey *et al.* (1998), technological history is full of examples of technologies that were believed to become revolutionary, but only had a limited impact on productivity growth and vice versa. Thus, the GPT framework has limited predictability and suffers from *ex post* bias. However, this is also true for the development block and TEP concepts. A clear set of criteria to distinguish among all possible technologies and not simply an *ex post* definition of the technologies that are of importance would be highly useful. However, so far, such criteria do not exist and thereby, it is evident that technological development cannot be analyzed without taking historical evolution into account.

The GPT and development block frameworks also have limitations when it comes to distinguishing revolutionary technologies from new technologies of lesser importance. As noted by David and Wright (2003), the suggested number of GPTs can be so many that the term revolutionary becomes grossly devalued. In the development block framework, all innovations form development blocks, but there is no attempt to make systematic distinctions between their relative importance for the subsequent growth path. Moreover, some innovations might give rise to hundreds of different development blocks, while others only result in a few. The TEP literature clearly distinguishes between "deeper conceptual breakthroughs" and subcategories presupposing the deeper change (e.g., the steam engine vs. railways and steamships, the internal combustion engine vs. motor vehicles and the integrated circuit vs. personal computers and the Internet).

According to the above comparison, the three theoretical concepts have some similarities, but also major differences. This reflects different views on how technological change should be analyzed. Nevertheless, if the three concepts are used together to define major technological breakthroughs since the eve of the Industrial Revolution in the UK, it is evident that the number of major breakthroughs is exceptionally small. Arguably, there are only four innovations that qualify: the steam engine, the internal combustion engine, electrification and the ICT revolution.

3. Previous research

Technological breakthroughs and productivity growth is a research field that has been subject to large international interest. The point of departure for this thesis is therefore the international debate about the information and communication technology (ICT) revolution. The basis for the ICT revolution was the transistor that was invented in 1947 by Bardeen, Brattain and Shockley. It became the basis for numerous electronic innovations, such as communication satellites, fiber optic cables, computers and cellular phones. Despite heavy investments in computers and other ICT equipment in the 1970s and the 1980s, productivity growth slowed down in many countries. For a long time, this was a puzzle to economists, referred to as the "Solow Paradox" after the Nobel Laureate Robert Solow's statement: "You can see the computer age everywhere but in the productivity statistics" (Solow 1987, p. 36).

In 1995, productivity growth in the US unexpectedly began to increase. This resulted in a debate on whether there was a link between investments in ICT and increased productivity growth. There were also a number of studies suggesting that ICT was finally having a positive impact on productivity growth. Based on the growth accounting methodology, Oliner and Sichel (2000) and Jorgenson (2001) showed that the use of ICT equipment together with improved production technology for computers accounted for approximately two-thirds of the increase in labor productivity growth in the US in 1996–99.

One of the drawbacks with the growth accounting framework is that it does not take spillover effects into account. Spillover effects are defined as TFP growth in the technology-using sectors resulting from the introduction of the new technology. Thus, it is essential to investigate whether productivity also increased in the industries using the new technology. Stiroh (2002) distinguishes between ICT-producing, intensive ICT-using and less intensive ICT-using industries.[1] According to Stiroh (2002), the industries investing heavily in ICT in the early 1990s experienced significantly larger productivity

[1] A similar framework is used by van Ark *et al.* (2003) to show that the key differences in productivity growth between Europe and the US are in intensive ICT-using services.

gains after 1995 than those that did not. Moreover, ICT-producing and intensive ICT-using industries accounted for approximately 80 percent of the productivity growth in the US economy in 1995–2000. Several firm-level studies also find evidence of a link between ICT use and productivity growth (Brynjolfsson & Hitt 2000).

Even though there is much evidence that ICT has had a positive impact on productivity in the US, there are also investigations that are more skeptical to the economic impact of ICT across industries. Gordon (2000) argues that the revival in productivity growth primarily occurred within durable goods production, particularly in the ICT-producing industry. He suggests that the effects of ICT have not been far reaching, but rather concentrated to a few industries of the economy. Thus, he questions whether the ICT revolution merits treatment as a basic industrial revolution compared to the great inventions of the past.[2]

Gordon's skepticism opens for comparing productivity growth following major technological breakthroughs. David (1990, 1991) investigates the impact of electrification on productivity growth in the early twentieth century. According to David (1991), the reorganization of production processes around a new technology turned out to be time consuming. David (1991) maintains that it was not until half of the factory mechanical drive capacity had been electrified that productivity growth in manufacturing began to increase.

The time lag hypothesis also holds for the steam engine revolution. According to Crafts (2004), the steam engine had little influence on labor productivity growth in the period 1760–1850. Moreover, Rosenberg and Trajtenberg (2004) argue that it was not until around 1850 when the Corliss steam engine was introduced in the manufacturing process, that steam started to have a substantial impact on productivity growth in the US. Thus, with these historical findings in mind, it is possible to argue in accordance with David

[2] Gordon (2004) withholds that electricity and the internal combustion engine were mega-inventions creating spin-offs such as air conditioning, roads, refrigerators and supermarkets. However, ICT spin-offs such as plasma TV screens, digital cameras and game-playing machines have not so far created the same quantum leap in consumer welfare as did the spin-offs of electricity and the internal combustion engine.

(1990) that it will take a considerable time before the productivity effects of computers and other ICT products are fully realized.

When productivity growth following different technological breakthroughs is compared, one of the most crucial issues is that productivity growth is correctly measured (Griliches 1988). To correctly measure productivity over time, it is necessary to measure the price change of different products. One of the major difficulties with measuring prices in industries with rapidly changing technologies is the problem of separating price changes from quality improvements (Gordon & Griliches 1997). During the recent ICT revolution, hedonic price indexes have emerged as a new method of measuring prices for computers and semiconductors and other ICT products.[3] Several of the papers included in this thesis investigate the effects of hedonic price indexes on productivity growth, both from a comparative and a historical perspective.

Most of the evidence presented for technological breakthroughs and productivity growth in this thesis is based on data for electrification and ICT in Sweden. Important contributions describing the electrification process in Sweden have been made by Hjulström (1940), Dahmén (1950), Glete (1983), Schön (1990, 2000), Norgren (1992), and Kander (2002). Moreover, extensive contributions by collecting historical data on output, factor inputs and prices have been conducted by Krantz & Nilsson (1975), Schön (1988), Ljungberg (1990) and Edvinsson (2005). For the ICT revolution, productivity data are based on the Swedish national accounts (Statistics Sweden 2005).[4]

This dissertation differs in a number of important aspects from previous Swedish research on technological breakthroughs and productivity growth. Three of the papers focus on comparing the productivity development following at least two major technological breakthroughs. Earlier Swedish research has primarily focused on describing the

[3] Triplett (2004) defines the hedonic price index as any price index making use of a hedonic function. A hedonic function is a relation between the prices of different product models, such as the various models of personal computers, and the quantities of characteristics in them.

[4] It has been more difficult to find data on the diffusion of ICT than on the diffusion of electric motors. One reason for this is that Statistics Sweden did not conduct any major surveys of the diffusion of ICT in Swedish manufacturing until 2000.

productivity growth pattern with respect to one technological breakthrough, namely electrification (see Schön 1990). Moreover, several papers compare productivity growth estimates at a very detailed industry level, which provides new knowledge of differences and similarities in productivity growth patterns, following major technological breakthroughs.

Another important difference is that productivity growth following technological breakthroughs is compared with other countries. Earlier Swedish research has primarily focused on productivity development in Sweden. By comparing Swedish results with results for other countries, new knowledge of the differences in productivity growth across countries after major technological breakthroughs is obtained. Moreover, this dissertation investigates the impact of new measurement methods on productivity growth following major technological breakthroughs. The impact of hedonic price indexes is investigated for industries producing the new technology during electrification and the ICT revolution. Moreover, one of the papers primarily focuses on the effect on productivity growth in the ICT-producing industries, depending on the measurement methods used in Sweden and the US.

Thus, by emphasizing the comparative perspective over time and across countries, the implications of new measurement methods on productivity growth and providing productivity estimates at the detailed industry level, this dissertation provides new knowledge of productivity growth following major technological breakthroughs.

4. Methods and Sources

4.1 Methods

To provide estimates of productivity growth, quantitative measures of output and factor inputs are necessary. Thus, the methods used throughout the thesis are primarily quantitative. Nevertheless, qualitative methods are also very important for understanding the impact of new technologies. Therefore, results from qualitative investigations based on secondary sources are used to substantiate the interpretation of the quantitative results.[5]

The quantitative methods are described in detail in the individual chapters. It is extremely hard, perhaps infeasible, to come up with "sharp" tests of causal effects from technological breakthroughs to significant productivity growth, in particular concerning historical technological breakthroughs. There are several reasons for this difficulty: there are long lags involved, the real world is exceedingly complex, and general patterns are unlikely to repeat themselves from one GPT to the next in a closely similar fashion. Moreover, to be able to test the impact of new technology on productivity growth, data on technology diffusion and productivity estimates at a detailed industry level or preferably at the firm level are needed. Unfortunately, it has not been possible to obtain data of sufficient quality for electrification and the ICT revolution in Sweden.

The lack of consistent data at the firm and disaggregated industry level implies that other quantitative methods were used. These methods were selected, depending on the questions investigated. The methods include estimation of labor and total factor productivity, growth accounting, decomposition of labor productivity growth and estimation of unit value ratios and hedonic price indexes.

4.2 Sources

All papers use estimates of labor and/or total factor productivity growth, which implies that data on output and factor inputs are necessary. For the ICT revolution, the data for Sweden are primarily based on Statistics Sweden (2005), while data for other countries are based either on secondary sources or statistical sources such as the OECD (2005)

[5] One example to illustrate that results from qualitative sources are important for understanding the impact of new technology is how the electric motor changed the design of the production process. According to Devine (1983), the first electric motors used in production just replaced steam engines. However, it was discovered that connecting a single electric motor to each machine resulted in further energy savings and increased production flexibility. Thus, the unit drive offered an opportunity to obtain greater output per unit of inputs. This example shows how qualitative results can be used to illustrate how new technologies resulted in increased productivity growth.

STAN database, the Groningen Growth and Development Centre (2006) 60-industry database or the Bureau of Economic Analysis (2004) GDP-by-Industry Accounts.

For the electrification, data on output for Sweden are based on primary data from Kommerskollegium (1906–1939) and data provided by secondary sources such as Ljungberg (1990) and Schön (1988). Data on the diffusion of new technology, wages etc. are based on Kommerskollegium (1906–39) and the Swedish statistical yearbook (1922–42). Moreover, data on prices of electric motors were collected in archives in Stockholm and Västerås – see ASEA (1900–35) and the Swedish Royal Library (1900–35). For earlier technological breakthroughs, such as electrification and the steam engine revolution outside Sweden, data are mostly based on secondary sources.

There are a number of problems with measuring productivity and therefore, it is important to be critical towards the data used. Historical data are often subject to substantial measurement problems and should therefore be used with caution. Mokyr (1993) asserts that in modern industrial societies, the construction of national income statistics gives rise to severe data problems; for eighteenth century Britain the problems are much greater and national income estimates can only be "controlled conjectures". Nonetheless, growth cannot be analyzed without them. Hence, when it is written that "the growth rate *was x* percent" during a certain period, this always means that the growth rate has been estimated to be *x* percent by the cited author(s) and that the reader should keep all possible problems due to data limitations in mind.

As long as numerous independent sources are used and the data are viewed with these caveats in mind, it can be argued that the quality and accuracy of productivity data for earlier technological breakthroughs are sufficiently high to warrant conclusions about productivity development and the diffusion of the technology in the economy.

5. Summarizing the thesis

This dissertation consists of four self-contained studies concentrating on the productivity development following major technological breakthroughs. All four studies are concerned with measurement issues of productivity. Three of the papers use a comparative historical perspective and primarily focus on some of the differences and similarities in productivity growth following each technological breakthrough. A fourth paper solely focuses on the ICT revolution and the problems associated with measuring productivity in the Swedish Radio, television and communication equipment (RTC) industry.

Paper 1, *Technological Breakthroughs and Productivity Growth* (with Magnus Henrekson), examines productivity growth following three major technological breakthroughs: the steam power revolution, electrification and the ICT revolution. The distinction between sectors *producing* and sectors *using* the new technology is emphasized. A major finding for all breakthroughs is that there is a long lag from the time of the original invention until a substantial increase in the rate of productivity growth can be observed.

There is also strong evidence of rapid price decreases for steam engines, electricity, electric motors and ICT products. However, there is no persuasive direct evidence that the steam engine producing industry and Electric machinery had particularly high productivity growth rates. For the ICT revolution, the highest productivity growth rates are found in ICT-producing industries. It is argued that one explanation might be that hedonic price indexes are not used for the steam engine and the electric motor. Still, it is likely that the rate of technological development has been much more rapid during the ICT revolution as compared to any of the previous breakthroughs.

In paper 2, *Do Hedonic Price Indexes Change History? The Case of Electrification*, I investigate whether hedonic price indexing would also have large effects on measured price and productivity during electrification. The hedonic methodology is used on historical data for electric motors in Sweden in 1900–35. The results show that PPI-deflated prices for electric motors decreased by 4.8 percent per year based on hedonic price indexes. This indicates that prices decreased considerably more for electric motors compared to total manufacturing.

Annual labor productivity growth in Swedish Electric machinery in 1919–29 becomes 12.1 percent if the hedonic deflators are used. Thus, there is strong evidence that productivity growth in the electric motor producing industry was very high during the 1920s. In contrast to Sweden, US annual labor productivity growth was only, according to current best estimates, 4.1 percent in Electric machinery compared to 5.3 percent in manufacturing in 1919–29. However, hedonic price indexes were not used to calculate US productivity. Finally, it is shown that the price decreases for electric motors in the 1920s were not on par with the price decreases for ICT-equipment in the 1990s, even if hedonic indexing is used in both cases.

Paper 3, *Parallel Development? Productivity Growth Following Electrification and the ICT Revolution*, compares labor productivity growth and the contribution to labor productivity growth in Swedish manufacturing during electrification and the ICT revolution. The paper distinguishes between technology-producing, intensive and less intensive technology-using industries during these two technological breakthroughs.

The results show that labor productivity growth and the overall contribution to labor productivity growth were considerably higher in technology-producing industries during the ICT revolution compared to electrification. For example, the relative contribution to labor productivity growth in manufacturing from the technology-producing industry was 3.4 percent in 1920–30 compared to 34.4 percent in 1993–2003. On the other hand, the relative contribution to aggregate labor productivity growth was considerably higher in intensive technology-using manufacturing industries during electrification. These findings have an important policy implication, namely that it is much more important how productivity is measured for ICT products in the 1990s than for electric motors in the 1920s.

Paper 4, *The Swedish ICT Miracle: Myth or Reality?*, investigates productivity development in Sweden in the 1990s. The results show that much of the recorded Swedish surge in labor productivity was due to the spectacular growth of the Radio, television and communication equipment (RTC) industry. However, the productivity growth of the RTC industry is very sensitive to value added price deflators.

Unlike Sweden, the US uses hedonic price indexes for semiconductors and microprocessors which are important intermediate inputs in the RTC industry. Estimates based on the US intermediate input price deflators for semiconductors and microprocessors suggest that the productivity growth of the Swedish RTC industry during the 1990s can be questioned. This implies that the productivity growth of total manufacturing has also been overestimated. The results for Sweden are also interesting for other countries such as Finland, Ireland and South Korea, where ICT-producing industries have contributed substantially to labor productivity growth.

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Part II

The Papers

PAPER 1

Technological Breakthroughs and Productivity Growth*

Harald Edquist and Magnus Henrekson

Abstract

This study consists of an examination of productivity growth following three major technological breakthroughs: the steam power revolution, electrification and the ICT revolution. The distinction between sectors *producing* and sectors *using* the new technology is emphasized. A major finding for all breakthroughs is that there is a long lag from the time of the original invention until a substantial increase in the rate of productivity growth can be observed. There is also strong evidence of rapid price decreases for steam engines, electricity, electric motors and ICT products. However, there is no persuasive direct evidence that the steam engine producing industry and Electric machinery had particularly high productivity growth rates. For the ICT revolution the highest productivity growth rates are found in the ICT-producing industries. We suggest that one explanation could be that hedonic price indexes are not used for the steam engine and the electric motor. Still, it is likely that the rate of technological development has been much more rapid during the ICT revolution compared to any of the previous breakthroughs.

JEL Classification: N10, O10, O14, O40

Keywords: Electrification, General Purpose Technologies, ICT revolution, Productivity growth, Steam power

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1. Introduction

According to many observers (e.g., Castells 1996, 1997; Greenwood 1997; Litan and Rivlin 2001) we have just experienced a technological revolution based on a breakthrough in information and communication technology (ICT). This revolution has already profoundly impacted the way we lead our lives and produce goods and services. Moreover, significantly higher rates of productivity growth were observed in the latter half of the 1990s compared to the 1970s and 1980s, in particular in the United States. This tendency was discernible in several other countries too, but on closer inspection it appears that it may only be true for the sectors producing the new technology. Still, towards the very end of the last millenium the ICT revolution carried high hopes for a new era, "a new economy", entailing a permanent upward shift in long-term productivity growth rates. Or as one extremely influential policymaker at the time put it: "the recent acceleration in labor productivity is not just a cyclical phenomenon or a statistical aberration, but reflects – at least in part – a more deep-seated, still developing, shift in our economic landscape" (Greenspan 1999, p. 3).

Throughout human history there have been a number of important technological breakthroughs. Schumpeter (1939) argued that new products and technologies, giving rise to "gales of creative destruction", would have a large impact on the economy for several decades. But how can we distinguish truly revolutionary changes from other changes? Bresnahan and Trajtenberg's (1995) concept of a General Purpose Technology (GPT) is useful in this context. They argue that whole eras of technical progress are driven by a few GPTs, characterized by pervasiveness, inherent potential for technical improvements and innovational complementarities giving rise to increasing returns to scale. GPTs are believed to play a decisive role for long-term productivity development as the new technology is diffused throughout different sectors of the economy (Helpman & Trajtenberg 1998). More specifically, Lipsey, Bekar and Carlaw (1998) maintain that a GPT has the following four characteristics: (1) wide scope for improvement and elaboration; (2) applicability across a broad range of uses; (3) potential usefulness in a wide range of products and processes; and (4) strong complementarities with existing or potential new technologies.

However, as noted by David & Wright (2003), based on these criteria Lipsey *et al.* (1998) come up with a list of GPTs that is so lengthy that the term revolutionary becomes grossly devalued. Hence, the GPT framework has limitations when it comes to distinguishing revolutionary technologies from new technologies of lesser importance. Moreover, it can be argued that the GPT framework also suffers from ex post bias. A clear set of criteria to distinguish among all possible technologies and not simply an ex post definition of the technologies that matter would be highly useful, but such an analysis is beyond the scope of this paper.

The GPT framework can be compared with the broader concept of Techno-Economic Paradigm (TEP) (Perez 1983; Freeman & Soete 1987). According to Freeman (1987) a TEP is a systematic relationship among products, processes, organizations and institutions that coordinate economic activity. Changes of TEPs are pervasive changes in technology affecting many branches of the economy and giving rise to entirely new sectors. A characteristic of this type of technical change is that it affects the input cost structure and the conditions of production and distribution for almost every branch of the economy. The definition of a GPT is more precise than the definition of a Techno-Economic Paradigm. However, the TEP literature clearly distinguishes between "deeper conceptual breakthroughs" and subcategories that presuppose the deeper change (e.g., the steam engine vs. railways and steamships, the internal combustion engine vs. motor vehicles and the integrated circuit vs. personal computers and the Internet).

By using the criteria suggested by the GPT and TEP perspectives on technological breakthroughs and focusing on the period since the eve of the Industrial Revolution in the UK, we reach the conclusion that the number of innovations that can rival the ICT revolution in importance is exceptionally small. Arguably, there are only three innovations that qualify: the steam engine, the internal combustion engine, and electrification.

But what impact does a major technological breakthrough have on the economy, notably on the level and rate of growth of productivity? How long does it take before the new technology has spread throughout the economy, fundamentally altering modes and patterns of production and consumption? The purpose of this paper is to explore these questions. In particular, we intend to explore whether each breakthrough is unique in its effects or whether one can detect a general pattern. We will compare the effects of three technological breakthroughs, namely the steam power revolution, electrification, and the ICT revolution.[1] Our paper is purely empirical and we have no pretension to make any conceptual or theoretical contribution to the GPT or TEP literature. The questions above are very broad, and more specifically we address the following questions:

(i) Have these technological breakthroughs been important for productivity growth?

(ii) What similarities and dissimilarities are there between technological breakthroughs?

(iii) What similarities can be found in the pattern of productivity growth after the breakthroughs and do they differ across countries?

(iv) Is productivity growth different in sectors *producing* the new technology compared to sectors *using* it?

Most studies that compare technological breakthroughs use either a macroeconomic perspective based on quantitative data or a microeconomic perspective based on qualitative data. We believe that the questions above must be analyzed with a combination of different perspectives, including the micro, macro, and industry levels. By combining these three perspectives and analyzing three major technological breakthroughs, it will be possible to gain new knowledge on the impact of different technological breakthroughs on productivity growth.

The paper is organized as follows. Section 2 consists of a methodological discussion related to our investigation. In sections 3–5 we examine each technological breakthrough

[1] We do not examine the impact of the internal combustion engine. The reason for this omission is purely pragmatic. The body of literature is meager and the introduction of the internal combustion engine largely coincides with electrification.

in detail and investigate its impact on productivity growth. Finally, we analyze our results from all three breakthroughs in order to find answers to the above questions. Our results show that it takes a long time from the moment of the original invention until a substantial increase in the rate of productivity growth can be observed. For the steam engine this was about 140 years (90 if the Watt steam engine is treated as the original innovation), while it was 40–50 years for electrification and the ICT revolution. We also find evidence of rapid price decreases for steam engines, electricity, electric motors and ICT products. This indicates rapid productivity growth in the industries producing the new technology. However, we cannot find direct evidence that the steam engine producing industry in the UK and the electric machinery industry in the US had particularly high productivity growth rates. For the ICT revolution the highest productivity growth rates were found for the ICT-producing industries throughout the six countries that we investigate.

2. Methodological Discussion

For the steam engine and electrification we will use secondary sources covering primarily Germany, Sweden, the UK and the US. For the ICT revolution we will present evidence from six different countries: Finland, France, Germany, Sweden, the UK and the US. Our investigation rests on empirical data mostly drawn from quantitative research. This raises issues concerning sources, concepts and productivity measurement. Before we delve into these matters it should be stressed that it is extremely hard, perhaps infeasible, to come up with "sharp" tests of causal effects from new GPTs to significant productivity growth, in particular concerning GPTs introduced long ago. There are long lags involved, the real world is exceedingly complex and general patterns are unlikely to repeat themselves from one GPT to the next in closely similar fashions. Instead we have to content ourselves with exploratory analyses with the aim of documenting whether identified patterns are consistent with fairly loosely formulated hypotheses.

2.1 Sources

For the ICT revolution we use primary data taken from the OECD Structural Analysis industrial database (STAN) (OECD 2003b) to analyze sectoral productivity in manufacturing for six countries.[2] The inclusion of Germany, France and Finland gives us a more complete picture of productivity development for Western European countries. Given that we include the three largest countries in Europe and two countries from northern Europe with a high degree of specialization in ICT-producing industries, we judge that our results can be seen as reasonably representative for the most recent breakthrough.

For the steam engine we primarily focus on the UK productivity development, while most of the evidence about electrification comes from the US. This is almost wholly due to data constraints. We are aware that this limitation may exclude important parts of the complex process of technological development and its implications for productivity growth. It is evident that technological processes may have evolved differently across countries, not least as a result of sizeable institutional differences.

Another limitation of our study is that we primarily, but not exclusively, focus on the impact of the new GPT on productivity in manufacturing, despite the fact that a large part of overall technological change takes place outside manufacturing. Difficulties in measuring productivity in the service sector and the ensuing lack of data force us to accept this limitation.

2.2 Data quality and measurement issues

We will present estimates both of labor productivity growth and total factor productivity (TFP) growth.[3] The data presented for earlier technological breakthroughs should be used

[2] For the US we also use data from the Bureau of Economic Analysis (2004) and the Bureau of Labor Statistics (2005).
[3] Labor productivity is usually based on data of value added and labor input. TFP estimates are based on data for value added, employment, hours worked, capital stock, and factor shares. TFP accounts for the effect of capital input on productivity, but the measure is derived on the assumption that the marginal products of labor and capital are equal to their respective market prices and that production is characterized by constant returns to scale.

with caution. Nevertheless, the available data make it possible to gain a better understanding of the general patterns of productivity development. Mokyr (1993) argues that if it is true that in modern industrial societies, the construction of national income statistics gives rise to theoretical and data problems, for eighteenth century Britain the problems are much greater and national income estimates can only be "controlled conjectures". Nonetheless, growth cannot be analyzed without them. Hence, when we write that "the growth rate *was* x percent" during a certain period this always mean estimated to be x percent by the cited author(s) given all the limitations of the study in question. As long as numerous independent sources are used and the data are viewed with these caveats in mind, we deem that the quality and accuracy of productivity data for earlier technological breakthroughs is sufficiently high to warrant conclusions about productivity development and the diffusion of the technology in the economy.

Another issue concerns the use of hedonic price indices.[4] The hedonic approach to price measurement is used to take quality changes into account. It redefines goods in terms of their characteristics so that modified or new models do not open up a new product category, but simply represent a new combination of characteristics (Scarpetta *et al.* 2000). There are no consistent hedonic price indices available for steam power and electrification.[5] For the ICT revolution hedonic price indices are used to adjust quality change in output for some countries. France, Sweden and the US use hedonic adjustments for some ICT products, while Finland, Germany and the UK do not (Scarpetta *et al.* 2000). Cross-country comparability of output and productivity could thus be impaired in sectors with rapidly falling prices such as the computer industry.

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[4] A hedonic price index is any price index that makes use of a hedonic function. A hedonic function is a relation between the prices of different varieties of a product, such as the various models of personal computers, and the quantities of characteristics in them (Triplett 2004). Hedonic price indices are further discussed in section 6.2.

[5] Section 4.3 includes estimates of hedonic price indices for electric motors based on Edquist (2005a).

3. The steam engine

3.1 The early development of the steam engine

The first widely used steam engine was invented by Thomas Newcomen in 1712. The Newcomen engine was mostly used in mining and consumed relatively large amounts of coal. It took several decades for the steam engine to become modified for productivity enhancing use and to diffuse among countries and industries. In 1765 James Watt developed the separate condenser (patented in 1769). Watt realized that if the main cylinder could be kept hot all the time, and condensation occurred in a separate cold vessel, fuel-savings could be fourfold (Mokyr 1994). The fuel-saving innovation made it possible to use the steam engine at locations where coal was scarce (Nuvolari & Verbong 2001). Thanks to Watt's innovation the steam engine could become an important power source in factories (Robertson 1955).

However, the Watt steam engine had serious limitations and it was not until reliable high pressure boilers were developed and put to effective use in the 1840s (the Lancashire boiler; Crafts 2004) that steam power could be deployed on a large scale in factories and transportation (railways and sea vessels). A further important improvement was the introduction of the Corliss engine in the early 1860s (Rosenberg & Trajtenberg 2004).[6] In particular, the switch to steam ships hinged crucially on the introduction of high-pressure steam and in fact steam ships did not replace sailing ships to any great extent until the late 1800s.

3.2 The diffusion of the steam engine

Table 1 presents crude estimates of total steam power capacity in 15 different countries in 1840–96.[7] According to *table 1* the US and the UK had the highest steam power capacity

[6] The Corliss engine had more advanced valves that allowed a much greater fuel efficiency and a uniform and uninterrupted flow of power.

[7] The steam power capacity estimates in *table 1* include capacity of fixed, railway and shipping steam power.

in 1840 totaling 760,000 and 620,000 horsepower, respectively.[8] Thus, these two countries accounted for more than 80 percent of the total world steam power capacity in 1840. At that point other large European countries, such as France and Germany, had a modest steam power capacity in relation to the UK and the US. However, the growth rate of steam power capacity was higher between 1840 and 1896 for all other countries included in *table 1*. Germany had the highest annual growth rate in steam power capacity (9.9 percent p.a.). Hence, most countries caught up with the UK and the US during the second half of the nineteenth century.

Table 1: Crude estimates of steam power capacity in different countries 1840–1896

Countries	*Thousands of Horsepower*						*Annual growth rate 1840–1896*	*Per 100 inhabitants in 1896/97*
	1840	*1850*	*1860*	*1870*	*1880*	*1896*		
Austria	20	100	333	800	1,560	2,520	9.0	6
Belgium	40	70	160	350	610	1,180	6.2	18
Denmark	n.a.	n.a.	10	30	90	260	n.a.	11
France	90	370	1,120	1,850	3,070	5,920	7.8	15
Germany	40	260	850	2,480	5,120	8,080	9.9	15
Italy	10	40	50	330	500	1,520	9.4	5
Netherlands	n.a.	10	30	130	250	600	n.a.	12
Norway	n.a.	n.a.	10	40	90	410	n.a.	20
Portugal	n.a.	n.a.	10	30	60	170	n.a.	3
Russia	20	70	200	920	1,740	3,100	9.4	3
Spain	10	20	100	210	470	1,180	8.9	7
Sweden	n.a.	n.a.	20	100	220	510	n.a.	10
Switzerland	n.a.	n.a.	90	140	230	580	n.a.	19
UK	620	1,290	2,450	4,040	7,600	13,700	5.7	34
US	760	1,680	3,470	5,590	9,110	18,060	5.8	25
The World	1,650	3,990	9,380	18,460	34,150	66,100	6.8	n.a

Note: The steam power capacity figures include capacity of fixed, railway and shipping steam power. The figures of steam power per 100 inhabitants are based on steam power capacity in 1896 and population figures in 1897. n.a. = not available.

Source: Mulhall (1899) and authors' calculations.

In 1896 the US and UK share of world steam power capacity had decreased to 48 percent. Nevertheless, the UK had the highest capacity per inhabitant in 1896/97. *Table 1* shows that the steam power capacity per 100 inhabitants in 1896/97 was 34 horsepower for the UK compared to 25 for the US. The corresponding figures for France and Germany were

[8] The standard unit for measuring power capacity is horsepower, where one unit is equivalent to a rate of 550 foot-pounds per second.

15 horsepower. Portugal, Russia and Italy had the lowest capacity per 100 inhabitants (see *table 1*). Hence the catch up was far from complete.

In manufacturing, the steam engine was first adopted in the UK, but the initial adoption was slow. According to Nuvolari & Castaldi (2003) the total number of steam engines installed in British mining and manufacturing in 1800 was only 2,191. The price difference between steam power and waterpower remained high. However, the cost disadvantage was gradually overcome by the mobility advantage and the increased efficiency of new generations of steam engines (Atack *et al.* 1980).

The initial adoption of steam power in US manufacturing was even slower. According to Atack *et al.* (1980) there was only one manufacturing plant using steam power in the US before 1776 compared to 130 in Britain. In 1838 the total steam power capacity in US manufacturing was 36,100 horsepower (Atack *et al.* 1980). A crude estimate of the corresponding figure for the UK was 350,000 horsepower (Tann 1988). These figures, although crude, suggest that by the 1840s the UK was far ahead of the US in steam power capacity in manufacturing. But once adoption gained momentum in the US it became rapid. By 1869 the total power capacity in US manufacturing had increased to 1,216,000 horsepower. Around 1820 waterwheels probably outnumbered steam engines by 100 to 1 in the US, but by 1870 this difference had narrowed to about 5 to 4 (Atack *et al.* 1980). These figures indicate that the breakthrough in the diffusion of the steam engine in the US manufacturing took place in the middle of the century. Fenichel (1966) shows that by 1899 steam accounted for four-fifths of total primary power capacity in US manufacturing.[9]

3.3 The steam engine and productivity growth

3.3.1 Steam power development in the UK

One way to investigate the impact of the steam engine on productivity growth is to analyze how TFP developed during the period when the steam engine was introduced in

[9] Primary power means the work done by "prime movers" which convert energy of nature directly into the energy of motion.

manufacturing. Most evidence indicates that the growth in output and TFP in the UK did not increase until the beginning of the nineteenth century (see *table 2*). This was more than 35 years after the invention of Watt's steam engine and 90 years after Newcomen's engine. Crafts (2004) argues that productivity growth did not increase substantially until the 1850s (see *table 2*).

Table 2: Growth during the British industrial revolution, 1760–1913 (percent p.a.)

Crafts	*Output*	*Capital stock*	*Labor force*	*Labor productivity*	*TFP*
1760–1780	0.6	0.25	0.35	0.25	0.0
1780–1831	1.7	0.6	0.8	0.9	0.3
1831–1873	2.4	0.9	0.75	1.65	0.75
1873–1899	2.1	0.8	0.55	1.65	0.75
1899–1913	1.4	0.8	0.55	0.85	0.05
Feinstein					
1760–1780	1.1	0.5	0.4	0.7	0.2
1780–1831	2.7	0.7	0.7	2.0	1.3
1831–1860	2.5	1.0	0.7	1.8	0.8

Note: Weights: Crafts: capital 0.4, labor 0.6; Feinstein: capital 0.5, labor 0.5.

Sources: Crafts (2002; 2004).

But can the increase in TFP and labor productivity growth in the UK be ascribed to the introduction of the steam engine? Several studies suggest that the impact of steam power on TFP growth was quite small (see Von Tunzelmann 1978 and Crafts 2004). Moreover, there are few indications that the steam engine had a substantial productivity-enhancing effect initially. One way of measuring the contribution of new technology is to use the concept of social savings. Social savings are usually measured as the gain in consumer surplus from the fall in costs due to new technology.[10] Estimates of social savings are invariably small for the steam engine. Von Tunzelmann (1978) estimates that the savings from using Watt's engines over Newcomen's in 1800 were approximately 0.11 percent of national income.

Crafts (2004) analyses the impact of steam engines on British labor productivity growth by using the growth accounting framework that Oliner and Sichel (2000) developed to

[10] This approach was applied to railroads in Fogel's (1964) famous study.

assess the impact of ICT on US labor productivity growth.[11] *Table 3* reports Crafts' estimates of the contribution of stationary steam engines, railways and steamships to British labor productivity growth in 1760–1910. *Table 3* shows that the impact of steam technology on labor productivity growth, measured as the increase in steam power capital in all sectors as a share of total income and TFP growth in the steam power industry as a share of total output, was 0.01–0.02 percentage points per year throughout the period 1760–1830.[12] During 1830–50, the contribution of steam technology increased to 0.2 percentage points of the annual labor productivity growth of 1.65 percent (see *table 3*).[13] In 1850–1910 the contribution of steam increased to 0.31–0.41 percentage points.[14]

Table 3: The contribution of steam technology to British labor productivity growth, 1760–1910 (percent p.a.)

	1760–1800	1800–30	1830–50	1850–70	1870–1910
Stationary Steam engines					
Capital deepening	*0.004*	*0.02*	*0.02*	*0.06*	*0.09*
TFP	*0.005*	*0.001*	*0.02*	*0.06*	*0.05*
Total	0.01	0.02	0.04	0.12	0.14
Railways					
Capital deepening	–	–	*0.14*	*0.12*	*0.01*
TFP	–	–	*0.02*	*0.14*	*0.06*
Total	–	–	0.16	0.26	0.07
Steamships					
Capital deepening	–	–	–	*0.02*	*0.05*
TFP	–	–	–	*0.01*	*0.05*
Total	–	–	–	0.03	0.1
Total Steam Technology	**0.01**	**0.02**	**0.20**	**0.41**	**0.31**

Note: The total steam technology contribution is based on the combined impact of capital deepening and TFP growth from stationary steam engines, railways and steamships.

Source: Crafts (2004).

[11] Oliner & Sichel (2000) identify the contribution from ICT to labor productivity growth as three types of ICT capital deepening (computer hardware, software and communication equipment) weighted by the shares of these types of capital in income and through TFP growth in the ICT-producing industry weighted by its share in gross output.
[12] Crafts (2004) does not calculate the rate of technical change in steam power as a TFP residual, instead he estimates the TFP as the aggregate social savings determined by the reductions in steam power costs.
[13] The average annual labor productivity growth of 1.65 percent refers to the years 1931–73.
[14] Annual labor productivity growth in Britain averaged 1.65 percent in 1873–1899 and 0.85 percent in 1899–1913 (see *table 2*).

The increase in the contribution of steam technology to labor productivity growth during the second half of the nineteenth century was to a great extent due to the large investments in railways during the period. For example, in 1830–1850 railways contributed 0.16 percentage points to labor productivity growth, while the contribution from stationary steam engines was estimated to be a mere 0.04 percentage points. It is important to point out that the railway industry was not *producing* steam engines, but rather *using* steam power technology. Moreover, it was not until after 1850 that the contribution of steam technology to labor productivity growth increased. However, the contribution from the stationary steam engine producing industry never exceeded 17 percent of total labor productivity growth.

Crafts' (2004) estimates show that the steam engine had little influence on labor productivity growth in the period 1760–1850. This suggests that 140 years after Newcomen's steam engine and 85 years after Watt's steam engine, no substantial TFP growth had taken place within the steam power *producing* industry. However, after 1850 steam technology started to contribute more to labor productivity growth. This time period coincides with the introduction of the high pressure steam engine. Steam engine capacity also increased rapidly during this period. In 1830 total steam power capacity in the UK was 160,000 horsepower compared to 2.06 million in 1870 and 9.65 million in 1907 (Kanefsky 1979; Crafts 2004). Hence, capacity in terms of horsepower grew by 5.5 percent p.a. in the 1830–1907 period.

Crafts' growth accounting approach also has shortcomings. Field (2006a) argues that the key message of the social savings approach is that in the absence of new technology the saving flows would have been invested elsewhere. This would have resulted in economic growth, although not quite as large. According to Fogel (1964) this meant canals and river dredging in the hypothetical absence of the railroad.[15] Fogel estimated that in 1890 GNP was 4 percent higher as a result of the railroad. The approach used by Crafts includes the portion of the effect of capital deepening on labor productivity that is the consequence of the accumulation of particular steam engine capital goods. As pointed out

[15] The approach assumes that aggregate saving flows would have been largely unaffected by the absence of the particular innovation under study.

by Field (2006a) the message of the Fogel approach is that in the absence of the steam engine, capital would have been accumulated in a slightly inferior range of capital goods. As a result, the growth accounting approach used by, *inter alia*, Crafts (2004) and Oliner and Sichel (2000) may overestimate the impact of the new technology.

However, it is also possible to argue that the growth accounting approach underestimates the impact of the steam engine, since it does not take account of spillover effects from the steam power *producing* industry to steam power *using* industries.[16] It is possible that increased flexibility and reliability due to the introduction of the steam engine in the production process could have generated substantial productivity growth in manufacturing industries using the new steam power technology. Nuvolari & Castaldi (2003) maintain that if the steam technology stimulated the generation of further technical or organizational innovations in sectors applying the new GPT, its economic impact cannot be appropriately assessed by means of growth accounting and social savings.

Table 3 indicated that the stationary steam engine producing industry did not have a large impact on aggregate productivity growth in 1760–1910 (see *table 3*). However, the steam engine may have had an impact on productivity in other sectors of the economy. Even though aggregate TFP growth was low in the UK it seems that some sectors experienced very high growth rates thanks to the introduction of the steam engine in their production processes. *Table 4* shows that steam power was used intensively in a few industries only. Throughout the period 1800–1907 mining, textiles, and metal manufactures accounted for more than 50 percent of the steam industrial power (Nuvolari & Castaldi 2003). However, important sectors including agriculture and the service sector excepting transport were in fact very slow at adopting the steam engine (Crafts 2004). This might be the reason why productivity growth stemming from the steam engine did not result in high aggregate productivity growth in the UK during this period.

[16] We define spillovers as increases in labor productivity in the using sectors beyond what one would expect from the capital deepening effect alone. In other words, spillover effects are the contribution to TFP growth in the using sectors resulting from the introduction of the new technology.

Table 4: Steam power by industry in the UK, 1800–1907

	1800		*1870*		*1907*	
Industry	Number of engines	%	Steam HP (power in use)	%	Steam HP (power in use)	%
Mining	1,064	48.6	360,000	26.2	2,415,841	26.5
Textiles	469	21.4	513,335	37.4	1,873,169	20.5
Metal manufactures	263	12.0	329,683	24.0	2,165,243	23.7
Food and drink trades	112	5.1	22,956	1.7	266,299	2.9
Paper manufactures	13	0.6	27,971	2.0	179,762	2.0
Building trades	12	0.6	17,220	1.3	347,647	3.8
Chemicals	18	0.8	21,400	1.6	182,456	2.0
Public utility (water-works, canals, etc.)	80	3.7	36,000	2.6	1,379,376	15.1
Others	160	7.3	44,375	3.2	309,025	3.4
Total	**2,191**	**100**	**1,372,940**	**100**	**9,118,818**	**100**

Source: Nuvolari & Castaldi (2003).

So which industries experienced the highest productivity growth? McCloskey (1981) estimates total factor productivity growth for a number of individual industries. McCloskey's figures have been widely criticized. Harley (1993) claims that McCloskey exaggerated productivity growth in several industries (cotton, wool, and shipping). In *Table 5* the average annual TFP growth for different industries in 1780–1860 are presented based on both McCloskey (1981) and Harley (1993). The figures indicate that productivity estimates for different industries must be analyzed with caution. Nevertheless, it is possible to draw some conclusions. It is, for example, evident that the textile industry had a high rate of productivity growth during this period. The textile industry was also an intensive user of steam power (see *table 4*).

Table 5: Crude estimates of annual total factor productivity growth for different UK industries, 1780–1860

	McCloskey	*Harley*
Cotton	2.6	1.9
Worsteds	1.8	1.3
Woolens	0.9	0.6
Iron	0.9	0.9
Canals and Railways	1.3	1.3
Shipping	0.5	0.5
Agriculture	0.4	0.7
All others	0.02	0.02

Sources: McCloskey (1981) and Harley (1993).

An important issue is how productivity increased in the sector producing steam engines.[17] By the size of the output shares for production of steam it is clear that the steam power producing industry was small compared to the rest of the economy. Crafts (2004) argues that in the period 1800–1840 there were few innovations in the steam power producing industry and the costs of steam engines did not fall. The subsequent period of rapid innovation resulted in large cost reductions. One of these innovations was the automatic variable cut-off mechanism of the Corliss steam engine that resulted in substantial improvement in fuel efficiency in the mid nineteenth century (Rosenberg & Trajtenberg 2004). Hence, the price of steam power had approximately halved by the mid-1850s and in 1910 the annual cost of steam horsepower had fallen by approximately 80 percent compared to the beginning of the nineteenth century (Crafts 2004). These observations suggest rapid productivity growth in the steam engine producing industry after 1850.

3.3.2 Steam power development in other countries

As already noted considerable time elapsed before the steam engine diffused in the US. According to Robertson (1955) the British sought to prevent export of the steam engine abroad. By 1838 only 5 percent of the total power used in US manufacturing was generated by steam engines. Rosenberg & Trajtenberg (2004) argue that it was not until around 1850 when the Corliss engine was introduced in the manufacturing process, that steam started having a substantial impact on productivity growth in the US. As in the UK, textiles, primary metals and machinery industries were the key industries in the process of industrialization. The fraction of power generated from steam increased in the textile and primary metals industries from 1/4 in 1870 to 1/3 in 1910. However, by then another key technology had started to change the production process in manufacturing.

For Finland, France, Germany, and Sweden we have been unable to uncover sufficient data to accurately investigate the impact of steam power on productivity growth. From a macroeconomic perspective the productivity and growth increases took place later in these countries compared to the UK (Fisher 1992). For the period 1820–70 GDP per capita growth in Germany was 0.7 percent p.a. The corresponding figures for Sweden and

[17] The estimates of TFP growth in the steam engine producing industry is based on an incomplete data set and should therefore be analyzed with caution.

France were 0.7 and 0.8 percent p.a., respectively (Maddison 1991). However, it has not been possible to investigate the importance of steam power for this development.

3.4 Concluding remarks on the development of steam power

Aggregate productivity growth did not accelerate until after 1850 in the UK, i.e. 140 and 85 years after Newcomen's and Watt's steam engines were invented. Hence, one cannot detect an effect on TFP until quite long after the invention had been made. Crafts & Mills (2004) note that "the contribution of steam power to industrial output and labor productivity was at its strongest *after* 1870". One interpretation of this is that the real potential of steam technology did not materialize until the high pressure steam engine had been invented. From this invention until sizable productivity effects could be detected no more than 20–40 years elapsed.

Furthermore, most of the productivity increases for the period appeared in sectors that were *using* the steam engine intensively, i.e. textiles and railways. The cost of steam power fell rapidly after 1840 as a result of a series of technical improvements of the original design. Notably, this opened the way for intensive use of the steam engine in the transportation sector. This may indicate a high productivity growth in the steam engine *producing* industry after all. However, the output of the steam engine producing industry remained less than 1 percent of total output in the UK throughout the 1760–1860 period. This could be one reason why the detectable effects of the steam engine producing industry remained small until the mid nineteenth century.

4. Electrification

We now switch the main focus from the role of the steam engine in British manufacturing to the US electrification process. The focus on US manufacturing is governed by data availability. To the greatest extent possible we also present complementary evidence from other countries, notably Sweden and the UK.

The invention of the dynamo was crucial for the nineteenth century electric industry. The principle behind the dynamo – the theory of electromagnetic induction – was discovered by Michael Faraday in 1831 (Byatt 1979). However, it took over forty years until the dynamo could be used commercially. The basic technological innovations raising energy efficiency in electricity generation to levels permitting commercial application occurred during 1856–1880 (David 1991). In 1867 a number of inventors came up with the idea of using an electromagnetic field energized by the dynamo itself. The Gramm dynamo was based on this principle and was able to generate electricity inexpensively enough for the commercial use of electric lightning. Other inventions such as the Swann-Edison lamp in 1879 and the Edison central generating station in New York and London in 1881 were also important for the diffusion of electricity. Moreover, innovations such as transformers and alternators made it possible to use alternating current instead of direct current, which substantially lowered costs for transmitting electricity.

4.1 Diffusion of electricity

Electric energy in the nineteenth century was produced by prime movers driven primarily by falling water (hydroelectric power) or by steam (thermal power).[18] Electricity is not a prime mover, but rather a form of energy that is easy to transport from the power source to the end user, which gives rise to efficiency and flexibility gains. The process of electrification began in the 1880s both in Europe and the US (Goldfarb 2005; Hughes 1983; Byatt 1979; Landes 1969). In the beginning, application was largely limited to lightning. Later, electrification spread to tramways and railways. Innovations such as the electric motor eventually came to revolutionize manufacturing. The large-scale use of motors in manufacturing started around 1900 in the UK. By 1907 electric motors in factories consumed about half of the total amount of electricity produced, and by 1912 factories used three times as much electricity as did traction (Byatt 1979).

The industries of other large European countries, such as Germany and France, were also rapidly electrified in the late nineteenth and early twentieth century (Milward & Saul

[18] According to Du Boff (1979) a prime mover is an engine that utilizes the potential energy of nature and directly converts it into energy of motion. Modern mechanical prime movers are the steam engine, the steam turbine, the hydro turbine, the internal combustion engine and the jet turbine.

1977). According to Landes (1969) the most striking achievements occurred in Germany. In 1907 the capacity of electric generators in Germany and the UK was roughly the same.[19] However, in 1925 the total capacity of German electric generators was 13,288,800 horsepower compared to 8,510,000 for the UK. Moreover, German companies such as Siemens & Halske and Allgemeine Elektrizitäts-Gesellschaft (AEG) became world leading manufacturers of electric equipment (Hughes 1983). In 1913, the German electric machinery industry was twice as big as that of Britain and only slightly smaller than in the US (Landes 1969).

Table 6: Available horsepower capacity in US manufacturing, 1869–1954 (thousand horsepower)

Year	*Total primary capacity*	*Non-electric capacity*	*Primary Electric motors*	*Secondary electric motors*
1869	2,346	2,346		
1879	3,411	3,411		
1889	5,845	5,845		16
1899	9,811	9,633	178	297
1904	13,033	12,605	428	1,089
1909	18,062	16,393	1,669	2,913
1914	21,565	17,858	3,707	4,684
1919	28,397	19,432	8,965	6,647
1923	32,667	19,426	13,241	8,796
1925	34,359	19,243	15,116	9,976
1927	38,236	19,336	18,900	11,201
1929	41,122	19,328	21,794	12,050
1939	49,893	21,077	28,816	16,011
1954	110,181	35,579	74,602	19,514

Note: Primary electric motors are those driven by purchased electricity. Secondary motors are driven by self-generated electricity and are excluded from total primary power available.

Source: Du Boff (1979).

In the US, electricity was first used as a commercial power source in 1882. The use of electricity in manufacturing increased slowly. In 1899, 4 percent of the total primary horsepower capacity in manufacturing used energy from purchased or firm-generated electric power. This had risen to 21 percent in 1909, 50 percent in 1919 and 75 percent in 1929 (Woolf 1984). *Table 6* presents figures from Du Boff (1979) for total primary

[19] Landes (1969) estimates are based on the industrial censuses in Germany and the UK in 1907. According to these estimates, the capacity of electric generators in the UK and Germany was 2,341,900 and 1,830,000 horsepower respectively. However, the British figures are based on capacity of engines and motors, while the German the power produced in regular operation.

capacity in manufacturing divided into non-electric capacity and electric motor capacity. The figures indicate that the rapid expansion of purchased and firm-generated electricity was somewhat more modest compared to what Woolf argues. Still, the expansion of primary and secondary electric motors was rapid.[20] Moreover, the adoption of electricity was very uniformly distributed across manufacturing industries (Jovanovic & Rousseau 2005).

Table 7 compares electrification in five manufacturing industries in the UK and the US. Even though the figures are not fully comparable some conclusions may be drawn. The figures point to large differences in the electrification process across industries in both countries. Industries such as engineering, shipbuilding and vehicles and chemicals were electrified much more rapidly compared to cotton textiles and coal mining. In iron and steel, coal mining, and cotton textiles Britain lagged behind the US. Byatt (1979) documents that these industries were slow in adopting electric motors in their production processes compared to both the US and Germany. Moreover, according to estimates by Broadberry (1997), the US/UK relative labor productivity level in the cotton industry increased from 151 in 1909/07 to 174 in 1914/12.

Why did Britain lag behind both Germany and the US in adopting electric motors in manufacturing? It appears that mining and textile industries that were early in adopting the steam engine in their production processes in Britain were much slower in adopting electricity compared, for example, to chemicals and engineering, or shipbuilding and vehicles (see *table 7*). One possible explanation for this is that the large investments in steam engines made those industries reluctant to invest in new electric technology. This suggests that technological choices are often path dependent and are not always socially optimal. Similar evidence from other areas supports this view (see David 1985). It is interesting to note that the US textile industry quickly switched from steam to electricity. In fact, Jovanovic & Rousseau (2005) find that the industries that quickly switched to electricity had been heavy users of steam. One parallel that comes to mind is the

[20] Primary electric motors are those driven by electricity purchased from utilities outside the manufacturing plant. Secondary motors are driven by electricity from generators and prime movers within the plant itself. They represent no addition to power available for use, since some of the plant's own power generating capacity must be employed to generate their electric energy (du Boff 1979).

Gerschenkron (1952) thesis that "relative backwardness" may facilitate economic growth, since it is easier to imitate the technologically leading countries. Similarly, a new GPT may be more readily adopted in a country where the previous GPT has not yet become so deeply entrenched.

Table 7: Degree of electrification in six industry groups: Britain and the US, 1904–1924 (percent)

Industry		*1904*	*1907*	*1909*	*1912*	*1919*	*1924*
Cotton textile	UK		5†		6		18
	US	7		19		53	
Iron and steel	UK		8		22		46
	US	12		25		46	
Engineering, shipbuilding	UK		43		74		92
and vehicles	US	32		65		72	
Chemicals and allied	UK		19		31		66
	US	16		42		59	
Coal mining	UK		4‡		20		43
	US	n.a.		20		53	

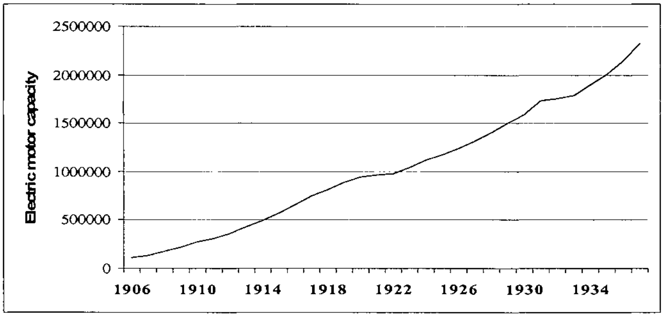
Note: †All textiles, ‡All mining

Source: Byatt (1979).

In Sweden, electricity started to be used in lightning in 1876. In 1885 there existed 111 dynamos with a capacity of 1036 horsepower (Hjulström 1940). The diffusion of electricity was rapid in Swedish industries. Sweden was also successful in innovation that permitted electricity to be transmitted over long distances without substantial power losses (Schön 1990). Initially, the primary source of electricity was steam power; in 1885 82 percent of the electricity produced came from steam power and the remainder from hydropower. In 1900 the relationship was largely reversed and 60 percent of the electricity was produced by hydropower (Hjulström 1940).

Swedish manufacturing rapidly adopted electricity in the production process. *Figure 1* shows the development of Swedish electric motor capacity in the manufacturing and handicraft industry. It is evident that Swedish manufacturing was electrified very rapidly at the beginning of the twentieth century. From 1906 to 1937 the power capacity of electric motors increased more than twenty fold. Which industries were then electrified most rapidly?

Figure 1: Electric motor capacity in the Swedish manufacturing and handicraft industries, 1906–1937 (horsepower)



Source: Hjulström (1940).

Table 8 shows that electric motor capacity increased in all industries throughout the period investigated. For the period 1913–1931 the most rapid expansion took place in wood and cork with a capacity increase of 452 percent. Food manufacturing, leather, furs and rubber products, and Non-metallic mining and quarrying also experienced increases exceeding 300 percent in their electric motor capacity in 1913–1931. The growth was slowest in textiles, wearing apparel and made-up textile goods – which is in accordance with the findings for the UK presented earlier.

Table 8: Electric motor capacity in different Swedish industries (horsepower) and percentage change, 1913–1931

	Electric motor capacity			*Percentage change*		
Industry	*1913*	*1920*	*1931*	*1913–1920*	*1920–1931*	*1913–1931*
Ore-mining and metal industries	158,984	384,699	582,253	142	51	266
Non-metallic mining and quarrying	22,470	56,252	92,535	150	65	312
Wood and cork	27,632	79,292	152,428	287	92	452
Paper and paper products, printing and allied industries	134,355	225,460	580,674	68	158	332
Food manufacturing industries	28,152	64,505	132,365	129	105	370
Textiles, wearing apparel and made-up textile goods	34,708	63,988	98,019	84	53	182
Leather, furs and rubber products	6,165	15,663	26,342	154	68	327
Chemicals and chemical products	13,134	31,691	45,033	141	42	243
Power, lighting and waterworks	6,095	17,461	22,916	186	31	276
Total	**431,695**	**939,011**	**1,732,565**	**118**	**85**	**301**

Note: The percentage change refers to the whole period, not percent p.a.

Source: Hjulström (1940).

4.2 Electricity and productivity growth

4.2.1 Productivity development in the US

Table 9 presents estimates of the compound annual growth rate of labor and TFP growth in the US non-farm business sector 1889–1948. Productivity growth is measured from peak to peak over the business cycle. According to Field (2003) choosing business cycle peaks for beginning and end points largely controls for the variations in capacity utilization that occur over the business cycle. The results show that labor and TFP growth was high during the period 1889–1901. In 1901–19 productivity growth slowed down and it did not start to increase until the 1920s. It is unlikely that electrification had a sizable effect on productivity growth in 1889–1901. For example, in 1899 only 4 percent of the total primary horsepower capacity in manufacturing used energy from purchased or firm-generated electric power (see section 4.1).

Table 9: Compound annual growth rates of labor and total factor productivity in the US private non-farm economy, 1889–1948

Period	*Labor productivity*	*TFP*
1889–1901	2.9	2.2
1901–19	1.7	1.1
1919–29	2.3	2.0
1929–41	2.4	2.3
1941–48	1.7	1.3

Note: Labor productivity is defined as output per manhour. LP = labor productivity; TFP = total factor productivity.

Source: Kendrick (1961) and authors' calculations.

Table 10 presents estimates of compound annual labor and TFP growth in US manufacturing for different periods. The estimates are based on Kendrick (1961) and Field (2006b).[21] These show large increases in both labor productivity and TFP growth in manufacturing for the period 1919–1929. The estimated growth rate in labor productivity and TFP was 5.5 and 5.1 percent, respectively.

[21] Kendrick (1961) provides estimates of TFP growth rates within manufacturing for the benchmark years 1929, 1937 and 1948. According to Field (2006b), 1937 is not a peak of the business cycle. Field has therefore calculated TFP growth rates within manufacturing for the subperiods 1929–41 and 1941–48. His calculations are based on Kendrick's estimates for output and labor input combined with capital input data from the Bureau of Economic Analysis.

Table 10: Compound annual growth rates of labor and total factor productivity in US manufacturing, 1889–1948

Period	*Field*		*Period*	*Kendrick*	
	LP	TFP		LP	TFP
			1889–99	1.4	1.1
			1899–1909	1.3	0.7
1889–1919	1.3	0.7	1909–19	1.1	0.3
1919–29	5.5	5.1	1919–29	5.5	5.1
1929–41	2.6	2.6	1929–37	2.0	1.5
1941–48	0.2	–0.5	1937–48	1.5	1.7

Note: Labor productivity is defined as output per manhour.

Sources: Field (2006b), Kendrick (1961) and authors' calculations.

As in the case of the steam engine several decades elapsed from the installation of the first power station producing electricity until there is evidence that electrification had a substantial impact on productivity growth within manufacturing. Why did productivity growth in manufacturing increase some 40–50 years after the introduction of the first commercial electric power stations? And which manufacturing industries experienced the highest productivity growth during this period?

David (1991) argues that it took considerable time for the manufacturing sector to adopt the new technology and use it efficiently. According to David electrification paved the way for a thorough rationalization of factory construction designs and internal layouts of production. One such rationalization was the shift from shafts to wires in the production system (Devine 1983). Before electricity was introduced, the production process was built around a large power source, such as a waterwheel or a steam engine. The power source turned iron and steel "line shafts" via pulleys and leather belts. Often all machines in an entire factory were linked to a single power source through these line shafts. The entire network of line shafts rotated continuously no matter how many machines were actually in use. If one line shaft broke, production stopped in the entire factory. It is evident that production systems built around a single power source were very energy consuming and lacked flexibility.

The first electric motors used in production just replaced steam engines and continued to turn long line shafts. But, it was soon discovered that large energy savings could be realized if a group of machines were driven from a short line shaft turned by its own electric motor. A further step was to connect a single electric motor to each machine. This unit drive innovation used less energy than the line shaft drive. Yet, the most important economic impact of the unit drive system was the increased production process flexibility that it entailed. Machines could be run only when needed. Moreover, machines could be organized in a natural sequence for manufacturing. In this way the unit drive offered an opportunity to obtain greater output per unit of inputs (Devine 1983).

The reorganization of production processes around a new technology turned out to be time consuming. David (1991) maintains that it was not until half of the factory mechanical drive capacity had been electrified that productivity growth in manufacturing began to increase. In addition, David and Wright (2003) point out in some detail that in order for electric power to gain full momentum a number of political and institutional changes were also necessary.

Table 11 shows the ratio of primary electric motor capacity to total primary capacity in US manufacturing. The data support David's hypothesis that it was not until the end of the 1920s that half of the mechanical drives had been electrified. To support his hypothesis David shows that there is a correlation between the change in the rate of productivity growth from 1909–19 to 1919–29 and the ratio of secondary electric motor capacity in 1929 to that capacity in 1919. A simple linear (OLS) regression of 15 industries confirms that the increase in secondary motor capacity accounts for approximately 25 percent of the variation in productivity growth from 1909–1919 to 1919–1929.[22] In subsequent work David and Wright (1999) provide more compelling evidence in support of the view that the productivity surge in the 1920s can be attributed to the diffusion of a new GPT rather than to multiple, largely unrelated sources.

[22] David's regression results are based on TFP estimates adjusted for energy inputs based on Woolf (1984). However, David's OLS regression is still significant when we run the regression with productivity estimates based on Kendrick's (1961) two input approach (available upon request).

Table 11: Electric motor capacity/total primary capacity in US manufacturing, 1899–1954 (percent)

Period	*Electric motor capacity/total primary capacity*
1899	1.9
1904	3.3
1909	9.2
1914	17.2
1919	31.6
1923	40.5
1925	44.0
1927	49.4
1929	53.0
1939	57.8
1954	67.7

Source: Du Boff (1979)

An interesting observation can also be made for the production of electricity and for Electric machinery. Woolf (1984) finds that there was a substantial increase in the rate of productivity growth in the sector *producing* electricity. In 1902 7.3 lbs of coal was needed to generate one kilowatt hour of electricity. In 1917 the figure had fallen to 3.4 lbs and by 1932 only 1.5 lbs were needed. *Table 12* presents figures from Kendrick (1961) on compound annual labor and TFP growth in different manufacturing industries in the US. According to these estimates the substantial productivity increase did not appear in the industry *producing* electric machinery.

For the period 1919–1929 annual TFP growth in US manufacturing was 5.1 percent, while TFP growth in Electric machinery was only 3.5 percent per year.[23] The change in TFP growth from 1909–1919 to 1919–1929 for manufacturing and Electric machinery is 4.9 and 3.2 percentage points, respectively. Hence, productivity growth increased substantially in the sector producing electricity, but not in the sector producing electric machinery. The productivity effects were materialized in sectors using electric machinery rather than in sectors producing it.[24]

[23] The compound annual labor productivity growth was 5.4 percent in US manufacturing, but only 3.9 percent in Electric machinery (see *table 12*).
[24] Kendrick (1961) provides estimates at the industry level from 1899. Therefore, it is possible that productivity increased in Electric machinery before 1899.

Table 12: Compound annual growth rates of labor and total factor productivity in US manufacturing, 1899–1937

Industry	*1899–1909*		*1909–1919*		*1919–1929*		*1929–1937*	
	LP	TFP	LP	TFP	LP	TFP	LP	TFP
Food	0.6	0.3	0	–0.4	5.2	5.2	0.9	1.5
Beverages	1.3	0.9	–6.6	–5.8	0.5	–0.2	13.5	14.1
Tobacco	1.7	1.2	5.9	4.8	7.0	4.3	7.3	6.1
Textiles	1.4	1.1	1.7	0.9	2.4	2.9	4.3	4.5
Apparel	0.9	0.7	3.3	2.7	3.9	3.9	2.1	2.5
Lumber products	–0.2	–0.4	–1.0	–1.2	2.9	2.5	–0.2	0.4
Furniture	–0.7	–0.8	–0.4	–0.5	4.2	4.1	0.3	0.5
Paper	3.0	2.4	0.5	0.3	4.9	4.5	4.4	4.2
Printing, publishing	3.9	3.8	3.2	3.0	3.7	3.7	2.6	2.6
Chemicals	1.3	0.6	–0.3	–0.7	7.9	7.2	3.0	3.0
Petroleum, coal products	3.0	0.7	1.8	–1.0	8.6	8.2	5.5	2.7
Rubber products	2.5	2.2	7.6	7.1	8.1	7.4	3.4	3.9
Leather products	0.5	0.1	0.9	0.5	2.5	2.9	3.2	3.5
Stone, clay, glass	2.7	2.2	1.0	0.7	6.1	5.6	1.7	2.2
Primary metals	3.7	2.6	–0.4	–0.5	5.6	5.4	–0.9	–1.3
Fabricated metals	2.8	2.3	2.0	1.8	5.0	4.5	0.5	1.0
Machinery, nonelectric	1.8	1.0	0.7	0.7	2.9	2.8	1.9	2.2
Electric machinery	1.3	0.6	0	0.3	3.9	3.5	2.8	3.1
Transportation equipment	1.3	1.1	7.4	6.8	8.7	8.1	–0.2	–0.4
Miscellaneous	1.1	0.8	–0.6	–0.6	5.3	4.5	2.2	2.8
Total Manufacturing	**1.3**	**0.7**	**1.1**	**0.3**	**5.4**	**5.1**	**2.0**	**1.9**

Note: Labor productivity is defined as output per manhour. LP = labor productivity; TFP = total factor productivity.

Source: Kendrick (1961) and authors' calculations

4.2.2 Evidence for other countries

Table 7 indicates that the UK lagged behind the US in the electrification of many important industries. According to Byatt (1979) the UK industry was very slow in investing in electric motors. The UK also lagged behind the US in terms of productivity growth. Floud (1994) estimates that annual TFP growth in the British economy decreased from 1.4 percent in 1856–1873 to 0.5 percent in 1873–1913. Labor productivity growth was slower in the UK relative to most other industrialized countries for the period 1913–1950 (Maddison 1991). Why then was the UK slower in adopting electricity?

Byatt (1979) argues that investments in electric motors had an impact on the UK economy, but not to the same extent as in the US. One reason for the late adoption of electricity in the UK could have been that other energy sources were cheaper than electricity. The UK had the most developed applications of steam as a power source and it was probably therefore more costly to invest in electricity. The evidence indicating that sectors with well-developed steam capabilities were slow in investing in electricity supports this explanation.

Table 13 shows annual labor productivity growth for 12 German manufacturing and handicraft industries in 1925–38.[25] The estimated total annual labor productivity growth in German manufacturing and handicraft was 2.5 percent in 1925–38.[26] Labor productivity was particularly high in metal producing, metal processing and chemical industries in the late 1920s. However during the 1930s, the rate of labor productivity growth decreased considerably in the metal producing and metal processing industries, while it remained relatively high in the chemical industry. However, throughout the period 1925–38, the chemical and metal processing industry had the highest annual labor productivity growth at 4.9 and 3.4 percent, respectively.

Table 13: Compound annual growth rate of labor productivity in different German industries, 1925–38

Industry	*1925–1929*	*1929–1938*	*1925–1938*
Stone and soil production	6.2	–1.9	0.6
Metal producing industry†	6.6	–0.3	1.8
Metal processing industry†	8.1	1.3	3.4
Chemical industry	6.7	4.1	4.9
Textiles	–0.8	3.5	2.2
Leather production	0.4	1.3	1.0
Clothing industry	–2.4	4.9	2.7
Wood products	0.8	0.9	0.8
Paper products	4.5	0.7	1.9
Food production	1.2	1.4	1.3
Gas, water and electricity	4.5	2.2	2.9
Construction††	–1.6	2.5	1.3
Total	**2.8**	**2.4**	**2.5**

Note: Labor productivity is defined as output per worker. †Employment was only available for the total metal producing and processing industry. It is therefore assumed that the change in employment was the same in these industries in 1925–38. ††Labor productivity estimates for Construction are for the 1926–38 period.

Source: Hoffmann (1965) and authors' calculations.

[25] The figures in *table 13* are based on estimates by Hoffmann (1965). The reliability of Hoffmann's estimates for the period 1850–1913 have been questioned (see Fremdling 1995; Burhop & Wolff 2005). Therefore, we only report estimates for the period 1925–38.

[26] Hoffmann (1965) does not present any comparable figures for the period 1914–24.

When it comes to productivity development in Sweden it appears that Sweden followed the US pattern. Schön (2000) shows that labor productivity growth in Swedish manufacturing increased from 1.5 percent p.a. in 1896–1910 to 2.9 percent in 1910–1935.[27] *Table 14* shows labor productivity growth for different industries in the Swedish manufacturing and handicraft industries in 1913–39. As in the US, labor productivity growth accelerated in 1919–1929. Chemicals and chemical products and power, lightening and waterworks experienced the highest rates of productivity growth in 1919–1929. However, as indicated in *table 8*, electric motor capacity did not increase the most in these industries. Thus, one cannot establish a clear correlation between labor productivity growth and the increased use of electric motors for different industries within Swedish manufacturing during the years 1919–1929.

Table 14: Compound annual growth rate of labor productivity in different Swedish industries, 1913–39

Industry	*1913–1919*	*1919–1929*	*1929–1939*
Ore-mining and metal industries	–2.8	4.3	2.5
Non-metallic mining and quarrying	–3.7	4.7	4.6
Wood and cork	0	0.3	1.0
Paper and paper products, printing and allied industries	–2.2	4.4	2.6
Food manufacturing industries	–0.1	3.0	1.8
Textiles, wearing apparel and made-up textile goods	–1.0	1.7	0.8
Leather, furs and rubber products	–2.8	0.1	0.8
Chemicals and chemical products	–6.3	11.2	3.8
Power, lighting and waterworks	–0.4	7.7	4.9
Total	**–1.7**	**3.8**	**2.4**

Note: Labor productivity is defined as value added per worker.

Sources: Schön (1988), Kommerskollegium (1913–39) and own calculations.

Finland's productivity growth was similar to the US and Sweden during electrification. According to Jalava & Pohjola (2005) annual labor productivity growth in the Finnish non-residential business sector increased from 1.9 percent in 1900–1913 to 3.1 percent in 1920–38. Moreover, they estimate that the use of electrical capital goods contributed 1.2 percentage points of the 4.5 percent growth in value added in 1920–38 compared to 0.4 percentage points of the 3.0 percent growth in value added in 1900–13. Hence, the

[27] Schön (2000) defines labor productivity as real value added per hour worked.

contribution of electrical capital goods increased from 13 percent of total value added growth in 1900–13 to 27 percent in 1920–38.

4.3 Price development of electric motors

We noted above that compound annual TFP growth in US manufacturing was 5.1 percent, while TFP growth in Electric machinery was only 3.5 percent in 1919–1929. This suggests that the industry actually producing the electrical equipment was not able to take advantage of its own technology to the same extent as other industries. *Table 15* shows the price development for a number of different electric motors (in terms of SEK/horsepower) produced by the Swedish company Luth & Rosen during the 1920s.

Table 15: Price series of electric motors produced by Luth&Rosén, 1919–1929 (SEK/horsepower)

No of hp	*3 hp*	*5 hp*	*7.5 hp*	*10 hp*	*15 hp*	*Index‡*	*CPI*	*Real*
Model	*C20*	*C21*	*C50*	*C51*	*C80*			*index*
1919	335	250	232	189	160	100	100	100
1920	319	237	215	175	148	93.5	100.4	93.2
1921	195	143	128	106	89	56.4	86.2	65.4
1922	157	114	100	84	53	42.6	69.8	61.1
1923	110	78	71	58	47	30.9	64.9	47.6
1924	122	86	74	63	48	33.3	64.9	51.3
1925	103	71	54	49	39	26.6	66.0	44.8
1926	103	71	54	49	39	26.6	63.8	41.7
1927	125	86	67	60	48	32.5	63.1	51.5
1928	112	78	61	53	44	29.3	63.4	46.2
1929	111	77	60	54	45	29.3	62.7	46.7

Note: ‡The index is an equally weighted price index of the 5 engines presented in the table above. All motors had the following characteristics: Alternating current, 1500 revolutions per minute, 190–500 V.

Sources: Ljungberg (1990), Myrdal (1933), Johansson (1967) and authors' calculations.

According to *table 15* the price of 3–15 horsepower electric motors fell rapidly in Sweden during the 1920s. On average prices fell by approximately 70 percent from 1919 to 1929. CPI calculations by Myrdal (1933) and Johansson (1967) indicate that total price deflation during this period was 37 percent. Hence, the real price of electric motors decreased substantially, which is a clear indication of productivity gains in the electric motor producing industry in Sweden.[28] These results call the productivity findings for US Electric machinery into question. It is reasonable to presume that the industry producing the electric motor also should be the industry that most rapidly understood how the electric motor could be used efficiently in the production process. Moreover, the increase in demand for the electric motor should have resulted in increased production and thereby allowed the industry to benefit from economies of scale.

Table 15 indicates that the price per horsepower fell more rapidly for electric motors with more than 5 horsepower. Moreover, a 15 hp electric motor in Sweden was much cheaper in 1929 compared to a 7.5 hp motor in 1919 both in nominal and real terms. To the extent that companies were buying electric motors with higher capacity during the 1920s, the real price of motor capacity installed fell even more than what is indicated by the price change of each motor category. Finally, it is likely that the quality of an electric motor increased during the 1920s in terms of reliability, duration etc. Ordinary price indexes do not take such quality improvements into account.

Edquist (2005a) constructs hedonic and matched model price indexes for electric motors in Sweden for the period 1900–35.[29] He finds that during the 1920s, PPI-deflated hedonic and matched model price indexes decreased by 4.8 and 3.7 percent per year, respectively. *Table 16* shows the estimated labor productivity growth for Electric machinery based on the hedonic and matched model price indexes estimated by Edquist (2005a).[30] According to *table 16*, annual labor productivity growth in the Swedish electric machinery industry in 1920–29 was 12.1 and 10.8 percent when hedonic and matched model deflators were used. Therefore, there is strong evidence that productivity growth in the Swedish electric motor producing industry was very high during the 1920s. However, it is still a puzzle why productivity did not increase more in US Electric machinery during the 1920s.

[28] It is important to point out that a price decline does not necessarily mean that productivity gains have been made. A price decline could also be due to increased competition in a specific market.
[29] The hedonic and matched model price indexes are based on prices and characteristics collected for slip-ring electric motors with 1–100 horsepower. Thereby, it is assumed that other electric motors would have a similar price development.
[30] Labor productivity has been defined as production value per person employed. Unfortunately it has not been possible to calculate labor productivity based on value added which implies that only single deflation is used to calculate productivity.

Table 16: Labor productivity growth in Electric machinery in Sweden, 1913–35 (percent p.a)

Year	*Growth rate*	
	Hedonic deflation	Matched model deflation
1913–1919	–7.2	–4.2
1920–1929	12.1	10.8
1930–1935	–2.5	–2.0
1913–1935	3.0	3.8

Note: Labor productivity is defined as production value per person employed.

Source: Edquist (2005a)

4.4 Concluding remarks on electrification

Evidence from the electrification process shows that productivity growth did not increase in US manufacturing until the 1920s, i.e. 40 years after the first electric power stations were established. Similar patterns can be observed in Sweden and Germany. Electrification took place in all the investigated countries in the 1880s. However, British manufacturing was slow in adopting the new technology, especially in industries that had a well-developed production system based on steam power technology.

In the US there was high productivity growth in the sectors producing electricity, but not in the industry producing electric machinery. Thus, it appears that the productivity effects were largely materialized in sectors *using* electric machinery rather than in sectors *producing* it. One possible explanation to these findings is that quality improvements were insufficiently considered when productivity was measured in the producing industries. As we will see below, this stands in contrast to contemporary estimates of productivity in ICT-producing sectors where a large part of productivity increases may be attributed to assessed improvements in quality.

5. The ICT revolution

5.1 Background

In 1947 Bardeen, Brattain, and Shockley invented the transistor. The transistor became the basis for numerous electronic innovations. Many of these innovations formed what is called the information and communication technology (ICT) sector. During recent decades the ICT sector has undergone a technological revolution. The development of numerous innovative technologies has given rise to a plethora of new products providing the basis for development within the ICT sector. Communication satellites in the 1960s, fiber optic cables in the 1970s and cellular telephones first introduced during the 1980s are significant examples of such product innovations. The Internet is yet another innovation that is believed by many to be a crucial driver of future economic growth (e.g., Litan & Rivlin 2001 and Lipsey *et al.* 1998).

In this section we investigate the economic impact of the ICT sector on productivity in the US and five European countries (Finland, France, Germany, Sweden, and the UK). The selection of countries was governed by data availability, but there is strong reason to believe that the conclusions for these countries are readily applicable to other European countries on a similar income level. The following questions will be discussed in depth: (1) What effect has ICT investments had on aggregate productivity growth? (2) In which industries can we find increased productivity growth? (3) Have there been any spillover effects from ICT-producing to the ICT-using industries?

5.2 What is ICT?

Before analyzing the economic impact of the ICT sector it is important to define ICT. We adhere to OECD's definition. For a manufacturing industry to be defined as an ICT industry, the manufactured products (OECD 2002b): (1) must be intended to fulfill the function of information processing and communication including transmission and display; and (2) must use electronic processing to detect, measure, and/or record physical phenomena or to control a physical process. For a service industry, products must be intended to enable the function of information processing and communication by electronic means.

Productivity measurements within the service sector give rise to several measurement problems.[31] Therefore we have chosen to focus on manufacturing (see *table 17*). For certain industries, the OECD definition of ICT-producing industries has been at a very disaggregated level. Therefore it is not possible to calculate value added and labor productivity at the disaggregated level used in *table 17*. The following industries are defined as ICT-producing: Office, accounting and computing machinery (ISIC 30), Electric machinery and apparatus (ISIC 31), Radio, television and communication equipment (ISIC 32) and Medical, precision and optical instruments (ISIC 33).

Table 17: ICT-producing industries in manufacturing

ISIC 3rd revision	*Economic activity*
30	Office, accounting and computing machinery
3130	Insulated wire and cable
3210	Electronic valves and tubes and other electronic components
3220	Television and radio transmitters and apparatus for line telephony and line telegraphy
3230	Television and radio receivers, sound or video recording or reproducing apparatus and associated goods
3312	Instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process equipment
3313	Industrial process equipment

Source: OECD (2002b).

5.3 The ICT Revolution and productivity growth

Despite heavy investments by firms in computers and other ICT technology in the 1970s and 1980s, productivity growth slowed down in most countries. The first oil crisis has been pointed out as one of the explanations for the productivity slowdown (Hulten 2001).[32] Nevertheless, the slowdown has remained a puzzle for economists, especially since it occurred when firms started to invest in computers that were believed to have a major positive effect on productivity.

[31] When measuring productivity in the service sector, it is difficult to determine whether quality improvements for produced services have occurred. This problem is further discussed in section 6. Moreover, many statistical agencies do not use any consistent method to measure prices in the service sector.

[32] The difficulty for the oil hypothesis has been explaining why low productivity growth rates persisted in the 1980s after oil prices collapsed.

During the 1990s, ICT investments were extremely large. During 1990–1996, US investments in computers rose by 28.3 percent per year (Jorgenson & Stiroh 1999). Sichel (1999) reports that the annual increase for computer investments during 1996–1998 was 41.8 percent. Calculations also show that ICT accounted for about half of the increase in real capital in the US during the period 1990–1996 (Andersson 2001). The available data for OECD countries show that ICT investments rose from less than 15 percent of total non-residential investment in the business sector in the early 1980s, to between 15 and 35 percent in 2001 (OECD 2004). Did these investments have any substantial impact on productivity growth in different countries?

Table 18: Average annual growth of GDP per person employed in selected countries, 1980–2001 (labor productivity)

Country	*1980–89*	*1990–95*	*1996–2001*
Finland	2.5	2.5	1.9
France	2.1	1.3	1.4
Germany	n.a.	2.2	1.6
Sweden	1.6	2.5	1.9
UK	2.2	2.0	1.6
US	1.5	1.2	2.1
EU–15	1.8	2.0	1.3

Note: Calculations for Germany use growth figures beginning in 1992 due to the reunification of Germany. Figures for the period 1980–1995 have been taken from Scarpetta *et al* and figures for the period 1996–2001 are based on OECD (1998), OECD (2000), OECD (2002a) and OECD (2003a). n.a. = not available

Sources: Scarpetta *et al.* (2000), OECD (1998), OECD (2000), OECD (2002a) and OECD (2003a).

In *table 18*, we present data for the average annual growth rate of labor productivity for the six economies we study, as well as average labor productivity growth for the EU countries.[33] It is evident that the US is the only country that experienced a significant increase in the growth rate of labor productivity in the late 1990s and early 2000s. None of the other economies shows a similar increase in productivity growth during the late 1990s. We can also see that average labor productivity growth in EU countries decreased substantially during the second half of the 1990s. In this respect, development in the EU on the whole has been the opposite of what has occurred in the US.

[33] The selection of 1996 as the initial year for the last period follows other productivity studies of the "new economy" such as Oliner & Sichel (2000) and Nordhaus (2001). The choice of final year is governed by data availability.

During 2001, the US and most EU countries experienced an economic slowdown. Falling growth rates called the narrow "new economy" concept into doubt. Many observers have associated the concept with bankruptcies among dotcoms and other firms. However, productivity growth in the US remained high, despite the general downturn in the economy (Council of Economic Advisers 2002). *Table 19* shows that growth in labor productivity as well as TFP growth increased considerably during the period 1995–2001 compared to 1973–1995. Figures in *table 19* are based on a model that takes the effects of the business cycle on productivity into consideration. According to these calculations, structural labor productivity growth increased by 1.7 percentage points between the periods 1973–1995 and 1995–2001.[34] The corresponding figure for structural TFP growth is 1.07 percentage points, i.e. a tripling of the pace in the 1973–1995 period.

Table 19: Annual growth rates of labor productivity and TFP in the US, 1973–2001

	1973–1995	*1995–2001*	*Change (percentage points)*
Labor productivity growth rate (percent)	1.39	2.60	1.21
– Business cycle effect	0.02	−0.46	−0.48
= Structural labor productivity	1.37	3.07	1.70
– Capital services	0.72	1.29	0.57
– Labor quality	0.27	0.31	0.04
= Structural TFP	0.37	1.44	1.07

Note: Labor productivity is the average of income- and product-side measures of output per hour worked. TFP is labor productivity less the contributions of capital services per hour (capital deepening) and labor quality. Productivity for 2001 is inferred from data for the first three quarters.

Source: Council of Economic Advisers (2002).

The productivity performance of the US economy has intensified the debate about the effect of ICT on productivity throughout the whole economy. Research results have shown that investments in ICT play an increasingly important role for productivity growth. In recent years, however, several researchers have pointed out that a dramatic increase in productivity has only been experienced in a few industries (Jorgenson & Stiroh 2000; Gordon 2000).

[34] The structural labor productivity growth is defined as labor productivity growth minus the growth which is due to business cycle effects.

5.4 Productivity growth: Industry evidence

Has ICT influenced productivity growth in the whole economy, or has productivity growth accelerated in just a few industries? To make an in-depth analysis, we present results from productivity calculations at the sectoral level for manufacturing. We begin by presenting detailed information for the US (*tables 20* and *21*).[35] For the other countries, we present information for those three industries with the highest rate of labor productivity growth in 1996–2000/01.

Table 20 indicates that the compound annual labor productivity growth rate increased considerably in US manufacturing in 1996–2000. Compound annual labor productivity growth increased from 3.7 percent in 1990–1995 to 4.5 percent in 1996–2000. Labor productivity growth increased in 13 out of 20 of the industries between 1990–1995 and 1996–2000. This could indicate a spillover effect from ICT-*producing* to ICT-*using* industries.[36] However, a closer inspection reveals two industries in the US with much higher growth rates in labor productivity in the 1990s: Office, accounting and computing machinery (OAC) (ISIC 30) and Radio, television and communication equipment (RTC) (ISIC 32). The compound annual productivity growth rate for these two industries in 1996–2000 was 31.1 and 20.8 percent, respectively.

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[35] In *table 20* labor productivity is calculated for the period 1980–2000 and is defined as production value per person engaged. The reason is that value added deflators were not available for all industries in the STAN database. In *table 21* labor productivity is calculated for the period 1990–2003 and labor productivity is defined as value added per person employed. *Table 21* is based on figures from Bureau of Economic Analysis (2004) and Bureau of Labor Statistics (2005).

[36] We define spillovers as increases in labor productivity in the using sectors beyond what one would expect from the capital deepening effect alone. In other words, spillover effects are the contribution to TFP growth in the using sectors resulting from the introduction of the new technology.

Table 20: Annual LP growth in US manufacturing industries, 1980–2000

Industry	*ISIC*	*1980–89*	*1990–95*	*1996–2000*
Food products and beverages	15	2.7	1.7	1.9
Tobacco products	16	1.5	4.3	0.3
Textiles, textile products, leather and footwear	17–19	2.6	4.0	5.5
Wood and products of wood and cork	20	2.0	–0.2	0.7
Paper and paper products	21	2.5	1.9	1.7
Publishing and printing	22	1.1	–0.3	1.5
Coke, refined petrol. products and nuclear fuel	23	2.7	2.7	3.4
Chemicals and chemical products	24	3.2	2.0	2.5
Rubber and plastic products	25	4.0	2.9	3.3
Other non-metallic mineral products	26	2.4	1.7	1.8
Basic metals	27	2.9	3.5	1.3
Fabricated metal products excl. mach. and equip.	28	1.9	2.4	1.9
Machinery and equipment	29–33	5.2	9.2	10.6
Machinery and equipment, n.e.c.	29	n.a.	3.5	1.7
Office accounting and computing machinery	30	n.a.	24.3	31.1
Electric machinery and computing	31	n.a.	5.7	3.0
Radio, television and communication equipment	32	n.a.	18.3	20.8
Medical, precision and optical instruments	33	n.a.	4.2	3.7
Motor vehicles, trailers and semi-trailers	34	4.4	2.7	3.9
Other transport equipment	35	0.9	0.8	3.5
Manufacturing and recycling n.e.c.	36–37	1.7	2.0	2.9
Total manufacturing	**15–37**	**2.9**	**3.7**	**4.5**

Note: Labor productivity is defined as production value per person engaged.

Source: OECD (2003b) and authors' calculations.

In *table 20* labor productivity is defined as production value per person engaged. Intermediate inputs are not deducted from the production value, which implies double-counting of intermediate inputs. Production value may therefore be a poor measure of output when industry trends are analyzed (Bailey 1986). *Table 21* presents estimates of compound annual productivity growth for different US manufacturing industries in 1990–2003 defined as value added per person employed.[37] *Table 21* confirms the result that the highest productivity growth took place in the industry producing computers and communication equipment in 1990–2003. The compound annual productivity growth for Computer and electronic products (NAICS 334) was 26.6 percent in 1996–2003.[38]

[37] The productivity estimates are based on Bureau of Economic Analysis (2004) and Bureau of Labor Statistics (2005). The BEA and BLS use the North American Industry Classification Standard (NAICS) instead of the International Standard for Industry Classification (ISIC) used by OECD (2003b). This implies that the estimates in *tables 20* and *21* cannot be directly compared.

[38] Computer and electronic products (NAICS 334) include computers and communication equipment.

Table 21: Compound annual labor productivity growth in different US manufacturing industries, 1990–2003

Industry	*NAICS*	*1990–95*	*1996–2003*
Food, beverage and tobacco products	311–312	4.0	–0.3
Textile mills and textile product mills	313–314	4.0	3.0
Apparel, leather and allied products	315–316	3.5	10.2
Wood products	321	–3.6	1.2
Paper products	322	0.8	1.1
Printing and related support activities	323	–0.2	1.0
Petroleum and coal products	324	6.6	3.2
Chemical products	325	2.3	3.8
Plastics and rubber products	326	3.7	4.0
Nonmetallic mineral products	327	3.8	2.5
Primary metals	331	3.8	3.5
Fabricated metal products	332	3.1	1.5
Machinery	333	–0.8	2.7
Computer and electronic products	334	19.1	26.6
Electric equipment, appliances and components	335	3.0	4.9
Motor vehicles, bodies and trailers, and parts	3361–3363	4.3	5.1
Other transport equipment	3364–3366, 3369	–2.2	1.8
Furniture and related products	337	2.0	–1.6
Miscellaneous manufacturing	339	1.3	3.6
Total manufacturing	**31–33**	**4.1**	**5.8**

Note: Labor productivity is defined as value added per person employed.

Sources: Bureau of Economic Analysis (2004) and Bureau of Labor Statistics (2005)

Results for the five European countries show much less evidence of spillovers to the rest of the economy. First, as already shown, there is no detectable increase in aggregate productivity growth compared to the mid 1990s. Second, compared to the US, there is little evidence of spillovers within manufacturing. *Table 22* reports the three industries with the highest rates of labor productivity growth during 1996–2000/01.[39]

In France, Sweden and Finland there were two ICT-producing industries that had the highest annual productivity growth. However, for Finland and Sweden OAC (ISIC 30) is not among the three sectors with the highest productivity growth. Instead, Electric machinery and apparatus (ISIC 31) had the second highest labor productivity growth in Finland and Medical, precision and instruments (ISIC 33) in Sweden. In Germany, OAC (ISIC 30) had the highest productivity growth for the period 1996–2000. However, RTC (ISIC 32) ranks only third, with an annual productivity growth of 14.0 percent. For the

[39] Information for Finland and Sweden is from 1996–2001 and for the UK from 1996–1999.

UK OAC (ISIC 30) holds first place, but there are no data available for Electric machinery and apparatus (ISIC 31) and RTC (ISIC 32).

Table 22: The three manufacturing industries with the highest annual growth rate of labor productivity growth in five European countries 1996–2000/01

Country	*ISIC*	*Growth*
Finland		
Radio, television and communication equipment	32	19.9
Electric machinery and apparatus	31	6.0
Basic metals	27	4.2
France		
Office accounting and computing machinery	30	21.2
Radio, television and communication equipment	32	19.9
Motor vehicles, trailers and semi-trailers	34	10.5
Germany		
Office accounting and computing machinery	30	18.0
Coke, refined petroleum products and nuclear fuel	23	16.9
Radio, television and communication equipment	32	14.0
Sweden		
Radio, television and communication equipment	32	25.0
Medical, precision and optical instruments	33	12.1
Motor vehicles, trailers and semi-trailers	34	6.3
UK		
Office accounting and computing machinery	30	7.5
Motor vehicles, trailers and semi-trailers	34	3.8
Other transport equipment	35	2.7

Note: Labor productivity is defined as value added per person engaged. Figures for Sweden and Finland cover the 1996–2001 period. Figures for Germany and France cover 1996–2000 period and figures for the UK are for the 1996–1999 period. For the UK labor productivity is defined as value added/per person employed.

Source: OECD (2003b) and authors' calculations.

In all European countries investigated, an ICT-producing industry had the highest productivity growth. For Finland, France and Sweden the industry with the second highest growth was also ICT-producing. In Germany RTC had the third highest labor productivity growth. The comparison for the UK is incomplete, because of lack of data for some industries.

5.5 Spillovers to the rest of the economy

Aggregate data show that the US had very high aggregate productivity growth during the second half of the 1990s relative to the preceding twenty-year period. However, more disaggregated data for manufacturing shows that high productivity growth rates were experienced in just a few industries, notably in the ICT-*producing* industries, while productivity growth in ICT-*using* industries remained at levels similar to previous periods. Gordon (2000) argues that the productivity revival in the US occurred primarily within durable goods production and particularly in the ICT-producing industries. Should we then expect spillover effects to ICT-using industries in manufacturing and non-manufacturing? Evidence from the two earlier breakthroughs suggests that the large productivity gains were not realized until long after the introduction of the new GPT.

David (2001) points out that the increase in TFP growth in the US in the 1920s was very evenly distributed across industries. In contrast, it appears that most of the productivity growth during the 1990s was very unevenly distributed across industries, most of it taking place in ICT-producing industries. Harberger (1998) makes a distinction between a "yeast-like" process of growth characterized by evenly distributed growth throughout most of the economy and a "mushroom-like" process with productivity growth in just a few sectors. David (2001) argues that the patterns of TFP growth were starting to move from a "mushroom-like" process to a "yeast-like" process in the late 1990s.

Recent studies of productivity performance and ICT suggest that ICT has had substantial impact on productivity in a wide range of different industries and not only in the ICT-producing industries. Stiroh (2002) and van Ark *et al.* (2003) distinguish between ICT-producing industries, intensive ICT-using industries and less intensive ICT-using industries.[40] Stiroh (2002) finds that in the US, the ICT-producing and the intensive ICT-using industries accounted for all of the productivity revival (after 1995) that can be attributable to the direct contributions from specific industries. Oliner & Sichel (2000) also attribute a crucial role to the manufacture of computers, but they do not find that it

[40] Stiroh (2002) defines an intensive ICT-using industry as an industry with above median ICT share of capital services in 1995. van Ark *et al.* (2003) largely base their distinction of ICT intensive and less ICT intensive industries on the definition provided by Stiroh (2002).

accounts for all of the productivity increase. They estimate that use of ICT equipment together with improved production technology for computers account for approximately two-thirds of the increase in productivity growth in the US.[41]

Europe lags the US in terms of productivity growth. Still, it appears as though productivity growth has increased in the ICT-producing industries also in Europe even though the pattern is somewhat different. Within manufacturing RTC (ISIC 32) has had astounding productivity growth in several countries, while computer manufacturing played a larger role in the US. The phenomenal growth in RTC is particularly pronounced in Sweden and Finland.

Which sectors have accounted for increased productivity growth noticeable at the macro level in the US and why has not aggregate productivity growth increased in Europe? It appears that parts of the economy outside of manufacturing in the US have had a higher increase in productivity than corresponding sectors in Europe. McKinsey Global Institute (2001) maintains that the greater part of the increase in productivity in the US economy is concentrated in three sectors in addition to the ICT sector (semiconductors included): retail trade, wholesale trade and financial services.

Table 23 shows that both the US and most EU countries experienced rapid increases in labor productivity in ICT-producing industries. According to van Ark *et al.* (2003) the contribution of these industries to aggregate productivity growth was slightly lower in the EU compared to the US. Moreover, the largest difference appears to have taken place in ICT-using services. According to van Ark *et al.* the differential between the US and Europe is heavily caused by different productivity development in retailing, wholesale trade and financial Services. Estimates show that 0.90 percentage points out of a total

[41] As pointed out in section III the growth accounting framework used by Oliner and Sichel includes the portion of the effect of capital deepening on labor productivity that is the consequence of the accumulation of particular ICT capital goods. Field (2006a) argues that this is problematic since capital would have been accumulated in slightly inferior capital goods in the absence of ICT. Moreover, the growth accounting approach does not take spillover effects into account. Nevertheless, according to Oliner & Sichel (2000) TFP growth in computer production and computer related semiconductor production alone accounts for one fourth of the increase in labor productivity growth 1996–99 compared to 1991–95.

productivity growth differential of 1.1 percentage points between the US and Europe in the late 1990s emanated from these industries.

Table 23: Annual labor productivity growth of ICT-producing, ICT-using and non-ICT industries in the EU and the US, 1990–95 vs. 1995–2000 (percent)

	Productivity growth				*GDP share*	
	United States		EU		2000	
	1990–95	1995–2000	1990–95	1995–2000	EU	US
Total Economy	1.1	2.5	1.9	1.4	100	100
ICT-producing industries	8.1	10.1	6.7	8.7	5.9	7.3
...ICT-producing Manufacturing	15.1	23.7	11.1	13.8	1.6	2.6
...ICT-producing Services	3.1	1.8	4.4	6.5	4.3	4.7
ICT-using Industries†	1.5	4.7	1.7	1.6	27.0	30.6
...ICT-using Manufacturing	–0.3	1.2	3.1	2.1	5.9	4.3
...ICT-using Services	1.9	5.4	1.1	1.4	21.1	26.3
Non-ICT Industries	0.2	0.5	1.6	0.7	67.7	62.1
...Non-ICT Manufacturing	3.0	1.4	3.8	1.5	11.9	9.3
...Non-ICT Services	–0.4	0.4	0.6	0.2	44.7	43.0
...Non-ICT Other	0.7	0.6	2.7	1.9	10.5	9.8

Note: †Excluding ICT-producing industries. Labor productivity is defined as value added per person employed. EU includes Austria, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Spain, Sweden and the United Kingdom, which represents over 90 percent of the EU GDP.

Source: van Ark *et al.* (2003).

Table 23 also shows that ICT-producing manufacturing and the ICT-using service sector were larger in the US compared to the EU, measured as a share of GDP. The ICT-producing manufacturing sector had a share of 2.6 percent of total GDP in the US compared to 1.6 percent in the EU. The ICT-using service sector share of total GDP was 26.3 percent in the US compared to 21.1 percent in the EU. Thus, the sectors where productivity growth increased most during 1995–2000 were relatively larger in the US.

5.6 Concluding remarks on the ICT revolution

The transistor was invented in the late 1940s, but computers and cellular phones did not become consumer products until the 1980s. Aggregate labor productivity growth increased in the US in the latter part of the 1990s. However, aggregate labor productivity growth did not increase to the same extent in the EU countries. Nonetheless, labor productivity growth was much faster in the ICT-*producing* industries compared to ICT-

using industries for the US and for the five European countries that we have investigated for the period 1996–2001. Moreover, the aggregate productivity gap between the US and the EU was mainly due to productivity differences in retailing, wholesale trade and financial services. One possible reason for this could be that the US has been faster than Europe in implementing institutional and political changes that facilitate the exploitation of the economic potential of the new GPT (Litan & Rivlin 2001).

6. Summary and conclusions

We have examined three technological breakthroughs and the development of subsequent productivity growth. We will now summarize and draw some conclusions from our investigation. Moreover, we discuss some measurement issues concerned with comparing productivity growth in different countries and for different time periods.

6.1 Patterns of productivity growth after major technological breakthroughs

When comparing technological breakthroughs it is important to keep in mind that every new technology has unique characteristics. Few technologies fulfill the requirements for being classified as a GPT or TEP. The three technological breakthroughs investigated here are different from each other. The interdependence between different technologies can also be highly complex. For example, electricity replaced the steam engine in the industrial production process, but the steam engine was also important initially as a primary source for producing electricity. Furthermore, the ICT revolution presupposed the existence of an extensive electricity network. These examples imply that technological breakthroughs cannot be analyzed solely as individual cases.

We have shown that some major technological breakthroughs have impacted importantly on productivity growth in manufacturing, but also on aggregate productivity. It also appears that the impact of different key technologies has differed substantially across countries and industries. However, one major similarity for all three technological breakthroughs is that the productivity effects took place a considerable time after the initial innovation. David (1990, 1991) argues that when considering technological paradigm shifts, with the potential to create the core of a new technological regime, a time scale of 40–50 years may be necessary for the full impact of productivity growth to become evident in the conventional indicators. Our findings for the steam engine and the ICT revolution support David's view. However, it took much longer from the time when the steam engine was invented until it had an impact on productivity growth (some 140 years) than for the electricity breakthrough and the ICT revolution, where 40–50 years elapsed before increases in manufacturing productivity growth rates could be observed. These findings suggest that it is not the technological invention that directly affects growth, but rather the additional innovations made to improve the new technology that is important for productivity growth (this will be discussed further below). Why does the process of additional innovation take so long? And what is the character of these innovations?

Even though there are similarities between the productivity pattern following major technological breakthroughs, there are also important differences among them. The steam engine did not have a substantial impact on aggregate productivity growth in the UK until the 1850s, i.e. 140 years after Newcomen's original invention. The steam engine was not adopted by all sectors in the economy, but it was intensely used in a few key industries such as textile, coal mining and transportation. These industries also appear to have had a higher than average productivity growth (McCloskey 1981; Harley 1993). There is no clear evidence that the productivity growth associated with the steam engine in the UK took place in the industries *producing* the new technology. However, even though there are no direct statistical observations of high productivity growth in the steam engine producing industry, the price of steam power decreased substantially around 1850. This is a strong indirect indication of high productivity growth in the steam engine producing industry.

Both quantitative and qualitative studies have provided evidence that electrification had a substantial but delayed influence on productivity growth in US manufacturing. Moreover, there was an increase in productivity in the electricity-producing sector. However, increased productivity growth was not discernible in the sector producing electric machinery. Kendrick (1961) suggests that compound annual TFP growth was 3.5 percent per year in the industry producing electric machinery in the 1919–1929 period, while manufacturing as a whole had a TFP growth of 5.1 percent p.a. during that period. This suggests that the productivity effects took place in sectors *using* electric machinery rather than in sectors *producing* it.

David (1991) pointed out the relationship between increases in the rate of productivity growth and investments in electric motors. The same results cannot be found for Sweden. Moreover, even if there were substantial investments made in machinery with electric motors there was no substantial productivity increase in this particular industry. This is a major difference compared to the ICT revolution, where productivity increased by far the most in ICT-producing industries. In section 4, it was shown that there was a substantial fall in real prices of Swedish electric motors in 1919–1929. Unlike the ICT revolution there are no consistent hedonic price indices for the periods covering earlier technological breakthroughs, which suggests that the productivity effects from earlier technological breakthroughs may be underestimated.

For the ICT revolution we have seen large increases in the productivity growth for the sector *producing* ICT technology during the 1990s. However, it has not been possible to find evidence of spillover effects to other manufacturing industries. One of the reasons for the high labor productivity growth for the ICT-producing industries could be that hedonic price indices are used when deflating the value added for these industries. Still, this cannot be the whole explanation, since there are some countries with high productivity growth in the ICT-producing industries that do not use hedonic price indices, i.e. Finland, Germany, and the UK.[42] Despite the productivity increase in the ICT-producing industries it is only in the US that aggregate productivity growth has been at a significantly higher level compared to earlier periods. The increase in the productivity growth differential between the US and the EU in 1995–2000 can mostly be explained by differential productivity growth in retailing, wholesale trade and financial services.

[42] Hedonic price indices are thoroughly discussed below.

Another interesting point is the difference between the intensity of ICT use among ICT-using sectors. The major difference in productivity growth between the EU and the US has arisen in service industries with a high ICT intensity. Evidence from the steam engine revolution suggests that the industries using steam power technology intensely were those that had the highest productivity growth increases. The same pattern was observed for the US economy during electrification; productivity growth increases took place disproportionately in sectors that increased their use of electric motors in the production process.

6.2 Measurement errors

For the six countries studied we have shown that a large share of aggregate productivity growth in manufacturing during the latter half of the 1990s occurred in ICT-*producing* industries. A crucial assumption behind this result is that there are no systematic measurement errors. However, there are a number of problems with measuring production and productivity and these problems are likely to have increased in recent decades.[43]

First, most countries in our investigation use double deflation to arrive at value added in fixed prices. Double deflation implies that the value of gross output and intermediate inputs are deflated separately with an output price index and an intermediate input price index, respectively. However, Finland has not introduced double deflation in their national accounts, which implies that inputs are not deflated separately. If double deflation were introduced in the Finnish national accounts, productivity for different industries would change. This especially holds for industries that are using inputs with rapidly shifting prices, like ICT products. Output of the ICT-producing industry is largely an input for other industries. This implies that the deflation of production value and value added in the ICT-producing industry greatly affects the distribution of productivity growth between ICT-producing and ICT-using industries.

[43] This problem was noticed by the so-called Boskin Commission (see Boskin *et al.* 1997), which calculated that the annual inflation rate in the US during the preceding quarter-century was overestimated by slightly more than one percentage point.

Second, it is almost impossible to construct completely true deflators for the ICT sector (Brynjolfsson & Hitt 2000), where technology changes rapidly. Nordhaus (1997) argues that capturing the impact of new technologies on living standards is beyond the practical ability of official statistical agencies. The quality of the goods that we consume today is much higher compared to the quality of "the same" goods a decade ago. Countries use different methods to account for the rapid quality changes that take place. Sweden, the US, and France – but not Finland, Germany and the UK – use hedonic price indices for some of the ICT products. This has so far resulted in larger estimated quality improvements and thus volume increases (Pilat & Lee 2001).

Different methods for capturing quality improvements can have a large effect on productivity. Edquist (2005b) shows that productivity levels in the ICT-producing industry in Germany, Sweden, and the US change substantially depending on which country's value added price deflator that are used. Since there are no consistent hedonic price indices for the industries producing steam engines and electric machinery, it is likely that if quality adjustments had been made for their output, recorded productivity growth would have been higher for those industries as well.

Edquist (2005a) constructs hedonic and matched model price indices for electric motors in Sweden for the period 1900–35. He finds that during the 1920s, PPI-deflated hedonic and matched model price indexes decreased by 4.8 and 3.7 percent per year, respectively. This is a strong indication of high productivity growth in the industry producing electric motors in 1919–29. Moreover, the difference between the hedonic and matched model price indices is only 1.1 percentage points. One reason for this is that the same quality characteristics are used for the hedonic and matched model price indices, i.e. speed, power and maximum voltage. It is likely, that productivity growth in Electric machinery would have been considerably lower if these quality aspects were not taken into account.

Third, the recent technological shift has given rise to enormous intangible investments in new business and production systems, personnel training, etc. Brynjolfsson & Yang (1997) estimate that each dollar invested in computer hardware is associated with intangible investments of 10 dollars. These intangible investments are usually treated as current costs and not as investments, which reduces value added and the growth rate (in the medium term).

Fourth, an increasing share of production consists of services where deflation is often more difficult than for goods, since a larger share of the value depends on intangible characteristics (degree of accessibility, customer adaptation, delivery time, etc.). van Ark and Smits (2002) argue that new product applications based on electricity were mainly concentrated to manufacturing, while the real challenge for ICT is to change the production processes in services. Research on the finance and health care sectors in the US has shown that measurement problems have led to underestimates of productivity growth (e.g., Cutler 2004).[44] Thus, there are measurement problems that can cause both an underestimate of aggregate productivity growth, and an overestimate of increases in ICT production.

6.3 Concluding remarks

Our empirical investigation of three different technological breakthroughs suggests that it takes a long interval from the time of the original invention until a substantial increase in the rate of productivity growth can be observed. For the steam engine this period was about 140 years (85 years if the Watt steam engine is treated as the original innovation), while it was around 40–50 years for electrification and the ICT revolution. On the other hand, if we consider the high-pressure steam engine as the innovation that paved the way for the real steam engine revolution, then the time lag from innovation to greater rates of productivity growth is no longer for the steam engine than for the two subsequent technologies that we examine.

From the theoretical literature on GPTs as well as from our investigation it seems as though both *innovational complementarities* and *technological dynamism* are crucial for

[44] Intuitively it is easy to understand that it can be particularly difficult to discriminate between price increases and volume in health care. When a new, more expensive drug replaces an existing drug, how should the cost increase be divided between increased effectiveness and increased prices? Perhaps the improved effectiveness is so great that there is actually a decrease in price, or the improvement is so marginal that almost all of the cost increase should be treated as a price increase.

productivity growth. This implies, that an invention by itself would have little effect on an economy if there is no scope for the users of the new technology to improve their own technologies, and if continuous innovational efforts would not increase the efficiency by which the generic function is performed. For example, innovations that made the steam engine more efficient had to occur before it was introduced in the industrial production process. Moreover, before electricity could be used in manufacturing several types of electric machines had to be invented.

A further explanation for the delayed productivity effects is that it takes time to develop organizational innovations, i.e. systems that permit organizations to use new technology efficiently. At first the new technology may often just be performing the same function as the old technology, and in this process a great deal of existing productive capital will be "creatively destroyed" which further tends to delay the point where positive productivity effects at the more aggregate level can be observed (Greenwood 1997). Political decisions may also be called for before the full potential of the new GPT can be reaped. There may be strong vested interests tied to the old GPT, which manage to block reforms that would facilitate the deployment of the new GPT.

Concerning the pattern of productivity growth after major technological breakthroughs we find evidence of rapid price decreases for steam engines, electricity, electric motors, and ICT products. This indicates rapid productivity growth in the industries producing the new technology. However, we cannot find strong direct evidence that the steam engine producing industry and Electric machinery had particularly high productivity growth rates. For the ICT revolution the highest productivity growth rates has been found for the ICT-producing industry. There is thus no clear evidence of any particular productivity growth pattern after major technological breakthroughs. We argue that one explanation for the high productivity growth rates in the ICT-producing industries could be that no hedonic price indexes were used for the steam engine and the electric motor. Further research is called for to investigate the impact on productivity growth if hedonic price indexes are used for steam engines or electric motors. Another explanation could be that the technological development of semiconductors and integrated circuits could not be matched by the steam engine or the electric motor. There is simply no equivalent to "Moore's law" for other technological breakthroughs than the ICT revolution.

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PAPER 2

Do Hedonic Price Indexes Change History? The Case of Electrification*

Harald Edquist

Abstract

Rapid price decreases for ICT-products in the 1990s have largely been attributed to the introduction of hedonic price indexes. Would hedonic price indexing also have large effects on measured price and productivity during earlier technological breakthroughs? This paper investigates the impact of hedonic and matched model methods on historical data for electric motors in Sweden 1900–35. The results show that during the productivity boom of the 1920s, PPI-deflated prices for electric motors decreased by 4.8 and 3.7 percent per year, depending on whether hedonic or matched model price indexes were used. This indicates high productivity growth in the industry producing electric motors in 1919–29. In contrast to Sweden, US annual total factor productivity growth was only, according to current best estimates, 3.5 percent in Electric machinery compared to 5.1 percent in manufacturing in 1919–29. However, hedonic price indexes were not used to calculate US productivity. Finally, it is shown that the price decreases for electric motors in the 1920s were not on par with the price decreases for ICT-equipment in the 1990s, even if hedonic indexing is used in both cases.

JEL Classification: L60, N60, O10, O14, O33, O40

Keywords: Hedonic price index, Electric motor, Productivity growth, Electrification, ICT revolution, General purpose technologies, Innovation

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1. Introduction

During the 1990s, prices of ICT-products decreased rapidly, which resulted in high productivity growth for ICT-producing industries.[1] In the 1990s, many statistical agencies began to use hedonic price indexes to measure quality adjusted price changes in ICT-products. This has given rise to a debate on whether hedonic price indexes overstate price decreases and productivity growth. According to Triplett (2004), hedonic price indexes have been criticized for creating rapidly falling prices, thereby resulting in overstated productivity figures for ICT-producing industries.

The ICT revolution is an example of a major technological breakthrough. Major technological breakthroughs are based on technologies that have been named General Purpose Technologies (GPTs) (Bresnahan & Trajtenberg 1995). According to the GPT literature, whole eras of technical progress are driven by a few GPTs, characterized by pervasiveness, inherent potential for technical improvements and innovational complementarities giving rise to increasing returns to scale. There are also other perspectives and theoretical approaches for analyzing major technological breakthroughs.[2] However, no matter which perspective is being used, one of the most crucial issues about technological breakthroughs is the ability to correctly measure their impact.

One of the main indicators for measuring the impact of new technology is productivity. In order to correctly measure productivity over time, it is necessary to estimate the price change of different products.[3] One of the major difficulties with measuring prices in industries with rapidly changing technologies is the problem of correctly estimating

[1] OECD (2002) defines the following industries as ICT-producing: Office accounting and computing machinery (ISIC 30), Insulated wire and cable (ISIC 313), Radio, television and communication equipment (ISIC 32), Instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment (ISIC 3312), Industrial process control equipment (ISIC 3313), Wholesale of machinery, equipment and supplies (ISIC 5150), Renting of office machinery and equipment (ISIC 7123), Telecommunications (ISIC 642) and Computer and related services (ISIC 72).
[2] See, for example, Freeman and Soete (1987).
[3] The change in prices is used to calculate value added and production value in constant prices, which are used to calculate labor and total factor productivity.

quality improvements. To deal with this problem, many statistical agencies use the so-called "matched model" methodology to adjust for quality changes in price indexes. Another way of taking quality improvement into account is to use a hedonic price index.[4] The hedonic methodology is extensively used for ICT-products in the US, while European countries have been slower in adopting hedonic methods (van Mulligen 2003).

Previous GPTs are, for example, the steam engine, the combustion engine and electrification. However, ICT is the only GPT where hedonic price indexes have been systematically used to estimate quality adjusted price changes. An important question is how matched model and hedonic price indexes would affect prices for products that were crucial for previous GPTs? This paper investigates the impact of different price indexes on electrification, which was the GPT preceding the ICT revolution. The analysis focuses on the effects on the electric motor, which was crucial for the electrification in manufacturing.

It is well known that the electric motor changed the production process in many different industries (Devine 1983). Moreover, there is a correlation between the change in electric motor capacity and the change in productivity growth in different US industries 1919–29 (David 1990, 1991). However, total factor productivity (TFP) growth did not increase more than 3.5 percent per year in US Electric machinery. This was clearly below the average annual TFP growth of 5.1 percent in US manufacturing in 1919–29.[5] Unlike the US experience of the 1920s, productivity growth during the 1990s was very high for ICT-producing industries in the US and many western European countries. Thus, during electrification, the highest productivity growth was found in industries *using* electric motors, while during the ICT revolution of the 1990s, the highest productivity growth was observed in industries *producing* ICT (Edquist & Henrekson 2004).

[4] For definitions and a detailed discussion of hedonic and matched model methodology, see sections 3.1 and 3.2.

[5] Annual labor productivity growth, defined as value added per person employed, was 5.1 percent in US manufacturing and 4.1 percent in Electric machinery in 1919–29. Productivity estimates are based on Kendrick (1961).

The question stated above is very broad. More specifically, I will address the following questions:

(i) Do hedonic price and matched model price indexes change the view of the productivity performance in the industry producing electric motors?

(ii) Do price changes differ for electric motors depending on whether the matched model or the hedonic methodology is used?

(iii) Can the price changes for electric motors during the 1920s rival the price changes for computers and other ICT-products during the 1990s?

To answer these questions, I construct hedonic and matched model price indexes for electric motors in Sweden 1900–35.

2. Electrification and the ICT revolution

2.1 Electrification

The invention of the dynamo was crucial for the nineteenth century electric industry. The principle behind the dynamo – the theory of electromagnetic induction – was discovered by Michael Faraday in 1831. However, the first commercial power stations were not introduced until the 1880s, when they started to operate in the US and many European countries. It was also around 1880 that the first electric motors, based on electromagnetic induction, began to be commercially produced. However, it took until the 1920s until productivity in manufacturing experienced higher rates of productivity growth (David 1991).

David (1991) argues that electrification paved the way for a thorough rationalization of factory construction designs and internal layouts of production. One such rationalization was the shift from shafts to wires in the production system (Devine 1983). Before electricity was introduced, the production process was built around a large-scale power source, such as a waterwheel or a steam engine. The first electric motors used in production just replaced steam engines and continued to turn long line shafts. However, it was soon discovered that there could be large energy savings if a group of machines were driven from a short line shaft turned by its own electric motor. A further step was to connect a single electric motor to each machine. This unit drive innovation used less energy than the line shaft drive and it also increased the flexibility of the production process. In this way, the unit drive offered an opportunity to obtain greater output per unit of inputs (Devine 1983). However, it took a long time before factories had been reorganized to take full advantage of the productivity effects of the electric motor.

Table 1 presents data from Kendrick (1961) on labor- and total factor productivity growth in different manufacturing industries in the US.

Table 1: Average annual labor and TFP growth in US manufacturing 1899–1937

Industry	*1899–1909*		*1909–1919*		*1919–1929*		*1929–1937*	
	LP	TFP	LP	TFP	LP	TFP	LP	TFP
Food	0.2	0.3	–1.0	–0.4	4.9	5.2	–0.5	1.5
Beverages	0.1	0.9	–6.9	–5.8	0.3	–0.2	13.2	14.1
Tobacco	1.4	1.2	5.6	4.8	6.8	4.3	5.4	6.1
Textiles	1.1	1.1	–0.1	0.9	3.0	2.9	0.9	4.5
Apparel	0.3	0.7	1.5	2.7	4.0	3.9	–0.6	2.5
Lumber products	–0.5	–0.4	–1.5	–1.2	1.9	2.5	–0.8	0.4
Furniture	–1.0	–0.8	–0.9	–0.5	3.9	4.1	–1.5	0.5
Paper	2.4	2.4	–0.4	0.3	5.3	4.6	1.6	4.2
Printing, publishing	3.3	3.8	2.7	3.0	3.9	3.7	0.3	2.6
Chemicals	1.1	0.6	–1.2	–0.7	7.5	7.2	1.6	3.0
Petroleum, coal products	2.2	0.7	0.7	–1.0	8.6	8.2	1.2	2.7
Rubber products	2.4	2.2	6.6	7.1	8.3	7.4	0.5	3.9
Leather products	0.2	0.1	–0.6	0.5	2.2	2.9	0.8	3.5
Stone, clay, glass	2.5	2.2	0.5	0.7	5.2	5.6	0.9	2.2
Primary metals	3.9	2.6	–1.2	–0.5	4.8	5.4	–2.9	–1.3
Fabricated metals	2.3	2.3	1.2	1.8	4.6	4.5	–0.8	1.0
Machinery, nonelectric	1.3	1.0	0	0.7	3.5	2.8	–0.3	2.2
Electric machinery	0.5	0.6	–0.9	0.3	4.1	3.5	0.5	3.1
Transportation equipment	1.0	1.1	5.7	6.8	9.1	8.1	–2.2	–0.4
Miscellaneous	0.8	0.8	–1.5	–0.6	4.9	4.5	1.4	2.8
Total Manufacturing	**1.0**	**0.7**	**0.2**	**0.3**	**5.1**	**5.1**	**0.3**	**1.9**

Note: Labor productivity is defined as output per person employed. LP=labor productivity; TFP=total factor productivity.

Source: Kendrick (1961).

According to these estimates, there was no substantial productivity increase in the industry producing Electric machinery. For the period 1919–29, annual TFP growth in US manufacturing was 5.1 percent, while TFP growth in Electric machinery was only 3.5 percent per year. The change in TFP growth from 1909–19 to 1919–29 for manufacturing and Electric machinery is 4.8 and 3.2 percentage points, respectively. Labor productivity growth in Electric machinery was 4.1 percent as compared to 5.1 percent in manufacturing. David (1991) shows there to be a correlation between the change in the rate of industry productivity growth from 1909–19 to 1919–29 and the ratio of secondary electric motor capacity in each industry in 1929 to that capacity in 1919. Hence, the productivity effects materialized in sectors *using* electric motors rather than in sectors *producing* it. This suggests that the industry actually producing the electric equipment was not able to take advantage of its own technology to the same extent as other industries.

When it comes to productivity growth, it appears that Sweden followed the US pattern. Schön (2000) shows that labor productivity growth in Swedish manufacturing increased from 1.5 percent p.a. in 1896–1910 to 2.9 percent in 1910–35.[6] *Table 2* shows labor productivity growth for different industries in the Swedish manufacturing and handicraft sector 1913–46. As in the US, productivity growth accelerated in the period 1919–29. Chemicals and chemical products and Power, lightening and waterworks experienced the highest rates of productivity growth in 1919–29. In the Swedish industry classification system, Electric machinery was included in the Ore- Mining and Metal industry. This industry had an annual labor productivity of 4.3 percent compared to 3.8 percent for total manufacturing and handicraft. It has not been possible to obtain estimates of labor productivity defined as value added per unit of labor for Electric machinery 1913–46.[7]

[6] Schön (2000) defines labor productivity as growth rates of real value added per hour worked.
[7] For productivity growth estimates for Electric machinery, based on production value instead of value added, see section 6.1.

Table 2: Average annual labor productivity growth for different Swedish industries, 1913–39 (percent)

Industry	*1913–1919*	*1919–1929*	*1929–1939*
Ore-mining and metal industries	–2.8	4.3	2.5
Non-metallic mining and quarrying	–3.7	4.7	4.6
Wood and cork	0	0.3	1.0
Paper and paper products, printing and allied industries	–2.2	4.4	2.6
Food manufacturing industries	–0.1	3.0	1.8
Textiles, wearing apparel and made-up textile goods	–1.0	1.7	0.8
Leather, furs and rubber products	–2.8	0.1	0.8
Chemicals and chemical products	–6.3	11.2	3.8
Power, lighting and waterworks	–0.4	7.7	4.9
Total	**–1.7**	**3.8**	**2.4**

Note: Labor productivity is defined as value added per person employed.

Sources: Schön (1988), Kommerskollegium (1913–39) and own calculations.

2.2 The ICT revolution

In 1947, Bardeen, Brattain and Shockley invented the transistor, which became the basis for numerous electronic innovations. Together, these innovations formed what is called the information and communication technology (ICT) sector. The development of numerous innovative technologies has given rise to a plethora of new products providing the basis for development within the ICT sector. Communication satellites in the 1960s, fiber optic cables in the 1970s and cellular telephones first introduced during the 1980s are significant examples of such product innovations. The Internet is yet another innovation believed by many to be a crucial driver of economic growth (Litan & Rivlin 2001 and Lipsey *et al.* 1998).

Table 3 shows labor productivity growth for different industry categories for the US and the EU in 1990–2000. According to *table 3*, the highest productivity growth by far for these countries in the 1990s was found in the ICT-producing industries. Annual labor productivity growth in ICT-producing manufacturing in 1995–2000 was 23.7 percent in the US and 13.8 percent in the EU, compared to 2.5 and 1.4 percent for the total of all these economies. These results clearly indicate that the highest productivity growth in these countries took place in the ICT-producing industry. Moreover, intensive ICT-using service industries increased considerably more in the US as compared to the EU 1995–2000.[8]

Table 3: Annual labor productivity growth of ICT-producing, ICT-using and non-ICT industries in the EU and the US, 1990–95 vs. 1995–2000 (percent)

	United States		*EU*	
	1990–1995	1995–2000	1990–1995	1995–2000
Total Economy	1.1	2.5	1.9	1.4
ICT-producing industries	8.1	10.1	6.7	8.7
...ICT-producing Manufacturing	15.1	23.7	11.1	13.8
...ICT-producing Services	3.1	1.8	4.4	6.5
ICT-using Industries†	1.5	4.7	1.7	1.6
...ICT-using Manufacturing	–0.3	1.2	3.1	2.1
...ICT-using Services	1.9	5.4	1.1	1.4
Non-ICT Industries	0.2	0.5	1.6	0.7
...Non-ICT Manufacturing	3.0	1.4	3.8	1.5
...Non-ICT Services	–0.4	0.4	0.6	0.2
...Non-ICT Other	0.7	0.6	2.7	1.9

Note: Labor productivity is defined as value added per person employed. †Excluding ICT-producing industries. EU includes Austria, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Spain, Sweden and the United Kingdom, which represent over 90 percent of the EU GDP.

Source: van Ark *et al.* (2003).

2.3 Electrification and ICT: A comparison of productivity growth

As stated in the introduction, electrification and ICT are General Purpose Technologies. A number of articles have shown there to be similarities in the productivity patterns after major technological breakthroughs.[9] One such similarity is that it takes a long time from the original invention until a substantial increase in the rate of productivity growth can be observed.[10] However, one major difference between electrification and the ICT revolution is that productivity during the 1990s started to increase considerably more in industries producing the new technology, while productivity did not increase substantially in the industry producing electric machinery in the US during the 1920s. Moreover, electricity in the US was adopted by all sectors at approximately the same time, whereas

[8] According to van Ark *et al.* (2003), the major difference in labor productivity between the EU and the US is due to productivity differences in the intensive ICT-using service sector, since it accounts for a much larger share of the total economies compared to ICT-producing industries.
[9] See, for example, David (1991) and Crafts (2002).
[10] According to David (1991), electricity was commercially produced in the 1880s, but productivity first started to increase in manufacturing in the 1920s. Moreover, Crafts (2004) shows that steam power contributed little to economic growth before 1830 and had its peak impact about a hundred years after the invention of James Watt's steam engine.

ICT diffused rapidly in some sectors and not-so-rapidly in others (Jovanovic & Rousseau 2005). Moreover, Gordon (2000) argues that productivity revival in the US primarily occurred within durable manufacturing and that there is no evidence of increases in productivity growth outside durable manufacturing.

Another difference between the productivity booms of the 1920s and the 1990s is that productivity is measured differently. Hedonic price indexes are used for ICT-products in the US and many European countries such as Sweden and France (Scarpetta *et al.* 2000). However, hedonic price indexes were not used by Kendrick (1961) to take quality change into account. Kendrick was well aware that changes in quality would affect productivity in some industries such as Electric machinery:

> "Here, it should be noted that quality change will be greater in some industries than in others. Thus, manufactured goods are more susceptible to quality improvements than are farm products; and within manufacturing the quality of automobiles and machinery, for example, has probably improved more than that of lumber and lumber products. This should be kept in mind in interpreting relative changes in output and productivity by industry." (Kendrick 1961 p. 43)

To investigate whether the use of hedonic price indexes would result in large price changes for electric equipment, I have collected data on prices and characteristics for standardized electric motors in Sweden 1900–35.[11] These data were used to construct hedonic and matched model price indexes for electric motors in Sweden.

3. Method

3.1 The hedonic methodology

Triplett (2004) defines the hedonic price index as any price index making use of a hedonic function. A hedonic function is a relation between the prices of different product

[11] Data have been collected for three phase alternating current slip-ring electric motors with an open construction and a frequency of 50 periods (see section 4).

models, such as the various models of personal computers, and the quantities of their characteristics. As indicated by the definition, hedonic price indexes may be computed in a number of ways. Here, the time dummy variable method is used. This method is the most common in research, but a number of alternative methods exist.[12]

According to van Mulligen (2003), the hedonic method was pioneered by Waugh (1928) and Court (1939) and was first applied in economic analysis by Griliches (1961). Court and Griliches, like many others, used the hedonic method to construct a price index for the automobile industry.[13] For electric motors, the hedonic method has been used to a very small extent. Ljungberg (1996) constructs hedonic price indexes for electric motors in Germany and the UK. For Sweden, Ljungberg uses a matched model price index. To my knowledge, no one has used the hedonic method on electric motors in Sweden and no one has compared a hedonic index with a matched model index for electric motors for any country.

3.1.1 The time dummy variable method

The time dummy variable method is known as a direct method, since the index number is directly estimated from the regression, without other calculations. The time dummy variable method uses a time dummy variable to measure the change of prices, given that different price characteristics are held constant over a certain time period. To illustrate this, let there be K characteristics of a product and let model i of the product in period t have the vector of characteristics $z_i^t \equiv \left[z_{i1}^t,\ldots,z_{iK}^t\right]$ for $i = 1,\ldots I$ and $t = 0,\ldots T$. Denote the price of model i in period t by p_i^t. A hedonic regression of the price of model i in period t on its characteristics set z_i^t is given by:[14]

$$\ln p_i^t = c_0 + \sum_{k=1}^{K} \ln a_k z_{ik}^t + \sum_{t=1}^{T} B^t D^t + e_i^t, \qquad (1)$$

[12] According to Triplett (2004), there are at least three other methods that can be used instead of the time dummy variable method. These are called the characteristics price index method, the hedonic imputation method and the hedonic quality adjustment method.

[13] See, for example, Raff & Trajtenberg (1997).

[14] In this paper, the double-log functional form is used to estimate hedonic price indexes; see section 3.1.3.

where D^t are dummy variables for the time periods, D^1 being 1 in period $t = 1$, and zero otherwise; D^2 being 1 in period $t = 2$, and zero otherwise, etc. The coefficients B^t are estimates of hedonic price changes. The price index for year t is directly estimated from the regression in equation (1) by taking the antilog of the estimated dummy coefficient B^t. The double-log functional form implies that an equally weighted geometric average of quality-adjusted relative price in two periods is estimated (see appendix A).

In equation (1), the dummy variables are used to compare prices in period 0 with prices in each subsequent period. This implies that the a_k parameters are constrained to be constant over the period $t = 0,\ldots T$. This is one of the main disadvantages with the time dummy variable method (van Mulligen 2003). However, this problem can be circumvented by only pooling data for consecutive periods. I therefore estimate the hedonic regression for two adjacent years at a time. This implies that parameters are only constrained to be constant for two adjacent years, thereby permitting a relatively unrestricted impact of changes in characteristics of prices. The estimates for each pair of adjacent years are then chained so that a price index is estimated for the whole 1900–1935 period.

3.1.2 Selection of characteristics

The selection of the characteristics that should be included in the regression model is one of the fundamental difficulties in hedonic studies. Selecting the right characteristics implies that the set of characteristics of electric motors that are the most important performance attributes for users must be identified. Moreover, it must be possible to measure the characteristics in a consistent fashion over time. The characteristics that are chosen should be able to enter the users' utility function. In this paper, a number of technical aspects of the electric motor will be selected. However, there are also important aspects for users, such as reliability, that are almost impossible to quantify. According to Gordon (1990), the most serious disadvantage of all price measurement methods is that it is not possible to measure changes in the relation between excluded and included quality dimensions. The result will be a bias, unless all excluded quality characteristics maintain a fixed relation with included characteristics.

The characteristics included for the electric motor are the speed determined as revolutions per minute, the power measured as horsepower and the maximum voltage measured in volts for which the motor can be used. I only include electric motors that are open slip-ring motors developed for three phase alternating current with a frequency of 50 periods (see section 4).[15] Since this kind of motor is the most basic type among electric motors, it is not necessary to distinguish between characteristics such as, for example, whether the electric motor is an open or closed model.

The three continuous characteristics included in the regression are listed, together with the price in price lists and are therefore believed to have played an important role for the price of electric motors in 1900–35. One characteristic that I do not include in the regression is a measure of the size of the electric motor. The primary reason for this is that most electric motors were used in factories in fixed positions. Therefore, it is likely that when an electric motor had been installed, its size did not matter for the production process and hence, for users. Moreover, size is closely correlated to power, which implies that much of the size effect would be picked up by the estimated coefficient of the power variable.[16]

One characteristic that would have been interesting to include in the regression is a measure of how efficiently electric motors use energy.[17] Unfortunately, it has not been possible to find consistent measures of energy efficiency.[18] Moreover, for the years 1913–17, some motors include ball bearings while others do not.[19] Therefore, a dummy variable for electric motors with ball bearings was used to test whether this had any

[15] There are no data available of the torque curves of the electric motors and it has therefore not been included as a price determining characteristic.

[16] Excluding the size of the electric motor also implies that multicollinearity problems are avoided to the largest possible extent.

[17] Electric motor efficiency is the ration between shaft output power and electrical input.

[18] It has been possible to include efficiency as an explanatory variable for a few adjacent years. The results show that for the adjacent years 1900–01, 1901–02, 1902–03, 1903–04, 1904–08, 1920–21, 1925–26, 1926–28, the estimated price does not differ by more than 3 percentage points when the efficiency variable is included. However, for the period 1908–13, the difference is 7.8 percentage points.

[19] Before 1913, there were no electric motors in the sample of this investigation that were equipped with ball bearings.

significant influence on the price. However, no significant influence could be noted from ball bearings. After 1917, ball bearings were used in almost all electric motor models.

3.1.3 Functional form

According to the theory of hedonic functions, the form of the hedonic function is an empirical matter (Triplett 2004). Therefore, a variant of the Box-Cox test was used to determine the functional form that best fitted the data.[20] The results clearly showed that the double-log form best fitted the data. Therefore, the hedonic regression was set up in the following fashion:

$$\ln p_i^t = c_0 + a_1 \ln(speed)_i + a_2 \ln(power)_i + a_3 \ln(\max voltage)_i + b^t(D^t) + e^t, \qquad (2)$$

where $t = \tau$ and $\tau + 1$, $\ln p_i^t$ is the logarithm of the price for model i and time period t, *speed* is measured in revolutions per minute, *power* is measured as horsepower and maximum *voltage* is measured in volts. D^τ takes the value of 0 and $D^{\tau+1}$ takes the value of 1.

Taking the antilog of the b^t coefficient, the percentage change between two different periods is immediately obtained.

$$\%\Delta QAprice = \exp(b^t) - 1, \qquad (3)$$

where *QAprice* is the quality adjusted price and *%Δ* is the percentage change. For small values of b^t, $\%\Delta QAprice \cong b^t$, but as b^1 grows larger, so does the difference between (*exp* (b^t) −1) and b^t.

[20] The test that was used for choosing between the linear and log-linear models was proposed by Pindyck & Rubinfeld (1998). This test is based on the least squares approach (see Pindyck & Rubinfeld (1998) pp. 278–279).

3.1.4 The shortcomings of hedonic price indexes

There are several shortcomings with using the hedonic method to adjust for quality change. It is important to point out that the purpose of this paper is not to investigate the accuracy of the hedonic method. Instead, this study tries to analyze and compare the results generated by hedonic and matched model methodology for electric motors in Sweden 1900–35. Nevertheless, it is important to be aware of the shortcomings with the hedonic method.

One major objection to using hedonic price indexes is that it is difficult to know what is measured. In the 1960s, there used to be an erroneous perception that the coefficients from hedonic methods represented user value as opposed to resource costs. Rosen (1974) showed that hedonic coefficients generally reflect both user values and resource costs. The ratios of these coefficients may reflect consumers' marginal rates of substitution and producers' marginal rates of substitution (transformation) for characteristics. This implies that there is an identification problem where the observed prices and quantities are jointly determined by supply and demand considerations and their underlying sources cannot be separated (ILO 2004).

A standard assumption in the theory of hedonic indexes is that there is perfect competition among firms producing the investigated product. In the case of imperfect competition, producers price their products above marginal costs, which results in price mark-ups. This implies that user value is still reflected in implicit prices, but that implicit prices give no clear indication of producer costs (van Mulligen 2003). The implication of imperfect competition in the electric motor industry in Sweden is further discussed in section 6.1.

For many types of goods, it can be very difficult to identify the characteristics that are associated with price. Criticism has been raised against too much subjectivism in choosing the characteristics. However, there is no other quality adjustment method where subjectivism is not a problem. According to Triplett (2004), constructing matched models also involves subjectivism. It is also argued that theory provides little guidance to help determine the appropriate functional form of hedonic equations. However, according to

Triplett, this criticism is misconceived, since the choice of functional form is entirely an empirical matter.

The examples above provide a short overview of the debate about hedonic price indexes. For a more detailed investigation and discussion, see Triplett (2004) and ILO (2004).

3.2 The matched model methodology

In theory, the matched model is constructed by comparing exactly the same model of specific products in two time periods. The agency chooses a sample of sellers and product models and collects a price for the initial period for each of the models. Then, in some second period, the agency collects the price for exactly the same models and sellers as in the first period.[21] The price index is computed by matching the price for the second period with that in the initial period. Models that cannot be matched are excluded. In practice, it is not always exactly the same models that are being compared. The statistical agency rather specifies the size of variation in product characteristics that is acceptable for a match and thereby decides whether matching is achieved. Small changes in quality that are judged to have inconsiderable effects on the price may be ignored. A "match" is thus not necessarily an exact match.

When statistical agencies match models based on different assessments, they also introduce a quality bias. This quality bias comes in two forms: inside the sample bias and outside the sample bias. The inside type of bias occurs when prices of non-identical products are matched. The outside kind of bias occurs when price changes of matched models are not representative of price changes of unmatched models. This bias is often strong if the share of matched models is low (van Mulligen 2003).

Here, the same quality characteristics are used for the matched model as for the hedonic model, i.e. speed, power and maximum voltage. Moreover, models with ball bearings have not been matched with models with other bearings. The matched model price index

[21] It is likely that some of the models that were collected in the first period do not exist in the second period. Moreover, some models may have changed slightly over the two periods. It is then up to the agency to decide whether the slightly changed model in period 2 can be matched with the model in period 1.

was constructed by calculating the geometric mean of the price change of all "matched" models over the two adjacent years that are compared. To construct a price index based on the matched model methodology for electric motors, it was necessary to allow for some variation in product characteristics. Therefore, I included all matches with a variation of 0.2 horsepower, 70 revolutions per minute and 600 volts.[22] If more than two models fulfilled these requirements, the two with the closest fit were matched. When it was not possible to determine which of the models had the closest fit, weight was used as a fourth characteristic to match models. Finally, if the weight was unknown, electric motor models produced by the same company were matched.

4. The data set

To construct price indexes for 1900–35, data on prices and characteristics of electric motors were manually collected from disparate sources. Data on prices and characteristics of electric motors were collected from price lists of different companies that manufactured and sold electric motors in Sweden 1900–35. The price lists were retrieved from the ASEA archives in Västerås and the Swedish Royal Library in Stockholm.

Unfortunately, it was not possible to collect prices and characteristics for every year in the period 1900–35. Therefore, the calculations of hedonic and matched model price indexes are based on data for the following years: 1900–04, 1908, 1913–21, 1924–26, 1928–31, 1933 and 1935. These observations provide good coverage of the years both before and during the productivity boom of the 1920s (see *table 1* and *2*). However, for the period 1900–13, the calculations of price indexes are based on observations for only a few years. Moreover, the estimated impacts of characteristics were kept constant over much longer time periods, 1900–13 compared to 1913–35.

[22] This illustrates that to construct matched models, a number of *ad hoc* adjustments about different characteristics must be made. This problem is likely to have increased for ICT-products. For example, for computers, there may exist over 20 different product characteristics to match.

There were a number of differences among electric motor models during the period investigated. One important difference was that some electric motors were manufactured for direct current and others for alternating current. These differences make it very difficult to compute a hedonic equation that can distinguish between all different electric motor models. Therefore, this investigation only includes three phase alternating current slip-ring electric motors with an open construction and a frequency of 50 periods. The reason for making these limitations is to minimize the differences between electric motors over time. It is probable that the difference in construction and design of closed and more advanced electric motors may grow much larger over time.

The power of the electric motors included in the sample varies between 1 and 100 horsepower. Price lists indicate that there were no standardized electric motors with more than approximately 500 horsepower.[23] However, price data and characteristics of electric motors with more than 100 horsepower could only be found for a few years and have therefore been excluded in the hedonic regressions.

Table 4 shows for which years and companies the data have been collected. The data cover motors from several companies. These companies are: ASEA, Luth & Rosén, Motorfabriken ECK, Svenska elektromekaniska AB, AEG and Siemens.[24] The two latter companies were German, while the others were Swedish. Most of the data were collected from ASEA, which was a very large producer of standardized electric motors in 1900–35 (Glete 1983). Data on characteristics and prices for two consecutive years are not necessarily from the same company. Thus, it is assumed that companies had the same price strategies for the adjacent years investigated. Qualitative evidence indicates that there was strong competition among electric motor manufacturers until 1925 (see section 6.1). However, it is probable that there were price differences, depending on for example

[23] It is probable that electric motors with more than 500 horsepower may have differed substantially in price, depending on the specifications by each user.
[24] ASEA is currently named Asea Brown Boveri (ABB) after a merger with the Swiss firm Brown Boveri in 1988. Motorfabriken ECK changed name to Elektriska AB Morén in 1925.

reliability and brand name. These types of quality aspects are difficult to measure by hedonic and matched model price indexes.[25]

Table 4: Companies, number of motors and average horsepower for the collected data of electric motors

Year	*Company*	*Number of motors*	*Average horsepower*
1900	ASEA, AEG	60	20.3
1901	ASEA	18	24.6
1902	ASEA	18	24.6
1903	ASEA	21	26.6
1904	ASEA; Luth & Rosén	125	28.8
1908	ASEA	56	30.5
1913	ASEA; Motorfabriken ECK	109	29.2
1914	ASEA	32	7.8
1915	Motorfabriken ECK	39	22.8
1916	ASEA	253	35.9
1917	Motorfabriken ECK	47	37.5
1918	Luth & Rosén	28	14.7
1919	Elektromekano	33	14.5
1920	Motorfabriken ECK; Luth & Rosén	120	28.1
1921	Luth & Rosén	82	35.9
1924	Elektromekano	22	17.7
1925	Luth & Rosén	78	36.8
1926	ASEA; Elektromekano	266	31.7
1928	ASEA; Luth & Rosén; AEG	151	20.2
1929	ASEA	128	15.8
1930	Luth & Rosén	55	19.2
1931	ASEA; AEG	240	23.8
1933	Siemens	66	8.2
1935	Elektriska AB Morén	74	17.0

Sources: ASEA (1900–35) and the Swedish Royal Library (1900–35).

Table 4 also shows the number and the average horsepower of the electric motors for each year. The sample of electric motors and characteristics include 2121 observations. The minimum number of observations for one single year is 18 for the years 1901 and 1902. Moreover, average horsepower differs between 7.8 and 37.5. Average horsepower is especially low for the years 1914 and 1933. This means that the samples for these years include many small motors as compared to other years. However, even if electric motors

[25] It is possible to use a dummy variable for different brand names. However, the data for electric motors for most years are based on only one company, which makes it difficult to use dummy variables for brand names in this paper.

with more than 20 horsepower are excluded in the regressions, the results remain robust for the adjacent years 1913–14, 1914–15, 1931–33 and 1933–35.[26]

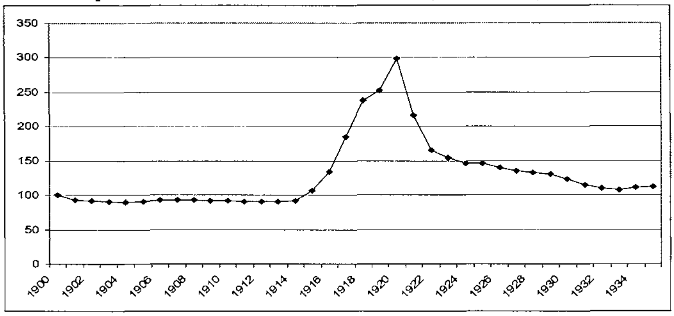
One problem with the collected data is that they are based on list prices. Calculations by Ljungberg (1990) of actual transaction prices of 30 electric motors purchased by the Swedish company Kockums 1914–20 indicate that list prices may differ from transaction prices. It is likely that list prices differed from actual transaction prices, especially when large quantities of machines were bought. Nonetheless, it is probable that the change in list prices is a good proxy for the change in actual transaction prices.

One additional problem with constructing price indexes for electric motors is that it was not possible to find data on the number of electric motors sold. Therefore, it was not possible to construct weighted price indexes for electric motors. All price indexes calculated are therefore unweighted price indexes, where all motors have equal weights. This might be a problem if motors that were not sold in large quantities differ substantially in price from motors that were sold in large quantities.

A producer price index (PPI) was used to convert current to constant prices. The PPI for Sweden 1900–35 is presented in *figure 1*.[27] The annual decrease in producer prices was estimated to be 0.6 percent 1900–1914. In 1914–20, producer prices increased by 21.6 percent per year. The annual decrease in producer prices was 16.2 percent in 1920–24, but only 2.4 percent in 1924–35. On average, producer prices increased by 0.3 percent per year 1900–35. *Figure 1* shows that World War I had a very large effect on producer prices. The unstable prices during World War I make it difficult to draw conclusions based on price estimates for this period.

[26] To ensure that there is no problem with heteroskedasticity, White heteroskedasticity-consistent standard errors and covariance have been used to estimate all regressions.
[27] The PPI is based on calculations by Ljungberg (1990).

Figure 1: Producer price index for Sweden 1900–35 (1900=100)



Source: Ljungberg (1990)

5. Results

5.1. The hedonic regression

The results of the hedonic regressions are shown in *table 5*. Both current and PPI-deflated prices were used for each pair of adjacent years and a dummy variable has been included for the later years. According to the results, the adjusted R^2 value varies between 0.90 and 0.99 depending on the period used for estimation. The R^2 values are very high as compared to many other regressions. However, according to Triplett (2004), it is not unusual that the R^2 value exceeds 0.9 in hedonic regressions. Nonetheless, a high R^2 value alone does not mean that there are no omitted variables. Knowledge of the product is often much more important for determining whether some important variable has been omitted from the regressions.

Most of the estimated coefficients are significant at the 1% level, which indicates that the selected characteristics are important for prices. Both the power and the maximum voltage coefficients have a positive effect on the price.[28] The coefficient of speed has a negative impact on price. This implies that low speed motors were more expensive than high speed motors. The estimated coefficients of the time dummy variable are significant for most years.

[28] For the period 1924–25, maximum voltage is excluded from the regression. The reason is that all electric motors in the sample were produced for a maximum voltage of 500 volts.

Table 5: Hedonic price regressions for alternating current slip-ring electric motors in Sweden 1900–35, adjacent years

Period	*Constant*	*Horsepower*	*Rate per minute*	*Max voltage*	*Time-dummy*	*Adj R^2*	*N*
1900–1901							
Current prices	7.59***	0.55***	–0.20	–0.03	–0.39***	0.93	78
Constant prices	7.59***	0.55***	–0.20	–0.03	–0.32***	0.92	78
1901–1902							
Current prices	5.04***	0.53***	–0.08	0.17***	–0.07**	0.99	36
Constant prices	5.04***	0.53***	–0.08	0.17***	–0.10***	0.99	36
1902–1903							
Current prices	6.31***	0.46***	–0.27**	0.19***	–0.09**	0.98	39
Constant prices	6.32***	0.46***	–0.27**	0.19***	–0.07**	0.98	39
1903–1904							
Current prices	8.61***	0.49***	–049***	0.05**	0.20***	0.94	146
Constant prices	8.61***	0.49***	–0.49***	0.05**	0.21***	0.94	146
1904–1908							
Current prices	8.75***	0.48***	–0.49***	0.06***	0.008	0.93	181
Constant prices	8.75***	0.48***	–0.49***	0.06***	–0.03	0.93	181
1908–1913							
Current prices	7.71***	0.48***	–0.46***	0.18***	–0.31***	0.96	165
Constant prices	7.71***	0.48***	–0.46***	0.18***	–0.28***	0.96	165
1913–1914							
Current prices	6.99***	0.49***	–0.50***	0.28***	–0.36***	0.98	141
Constant prices	6.99***	0.49***	–0.50***	0.27***	–0.37***	0.98	141
1914–1915							
Current prices	8.53***	0.50***	–0.50***	–0.03	0.34***	0.99	71
Constant prices	8.53***	0.50***	–0.50***	–0.03	0.20***	0.99	71
1915–1916							
Current prices	5.75***	0.49***	–0.27***	0.20***	0.36***	0.98	292
Constant prices	5.75***	0.49***	–0.27***	0.20***	0.12***	0.98	292
1916–1917							
Current prices	6.34***	0.50***	–0.30***	0.19***	1.10***	0.98	300
Constant prices	6.34***	0.50***	–0.30***	0.19***	0.78***	0.97	300
1917–1918							
Current prices	10.15***	0.52***	–0.63***	0.11***	–0.03	0.97	75
Constant prices	10.15***	0.52***	–0.63***	0.11***	–0.28***	0.98	75
1918–1919							
Current prices	9.10***	0.50***	–0.51***	0.15***	–0.03	0.98	61
Constant prices	9.10***	0.50***	–0.51***	0.15***	–0.09***	0.98	61
1919–1920							
Current prices	8.48***	0.47***	–0.54***	0.29***	0.12***	0.94	153
Constant prices	8.48***	0.47***	–0.54***	0.29***	–0.05	0.93	153

Note: Significant at 1% = ***, 5% = ** and 10% = *. White heteroskedasticity-Consistent Standard Errors and Covariance.

Sources: ASEA (1900–1935), the Swedish Royal Library (1900–1935) and own calculations.

Table 5: (continued)

	Constant	*Horsepower*	*Rate per minute*	*Max voltage*	*Time-dummy*	*Adj R^2*	*N*
1920–1921							
Current prices	8.62***	0.51***	–0.46***	0.18***	–0.55***	0.94	202
Constant prices	8.62***	0.51***	–0.46***	0.18***	–0.23***	0.93	202
1921–24							
Current prices	8.98***	0.55***	–0.46***	0.03	–0.77***	0.98	104
Constant prices	8.98***	0.55***	–0.46***	0.04	–0.38***	0.98	104
1924–25							
Current prices	8.78***	0.58***	–0.52***	–	0.15***	0.97	100
Constant prices	8.78***	0.58***	–0.52***	–	0.15***	0.97	100
1925–26							
Current prices	8.02***	0.53***	–0.55***	0.21***	–0.12***	0.96	344
Constant prices	8.02***	0.53***	–0.55***	0.21***	–0.08***	0.96	344
1926–28							
Current prices	7.93***	0.54***	–0.55***	0.19***	–0.17***	0.94	417
Constant prices	7.93***	0.54***	–0.55***	0.19***	–0.12***	0.94	417
1928–29							
Current prices	8.82***	0.56***	–0.53***	–0.0009	0.19***	0.90	279
Constant prices	8.82***	0.56***	–0.53***	–0.001	0.22***	0.90	279
1929–30							
Current prices	8.42***	0.52***	–0.53***	0.10	–0.33***	0.93	183
Constant prices	8.42***	0.52***	–0.53***	0.10	–0.28***	0.93	183
1930–31							
Current prices	6.66***	0.55***	–0.47***	0.25***	0.05**	0.95	295
Constant prices	6.66***	0.55***	–0.47***	0.25***	0.12***	0.95	295
1931–33							
Current prices	6.43***	0.54***	–0.43***	0.26***	0.18***	0.94	306
Constant prices	6.43***	0.54***	–0.43***	0.26***	0.24***	0.94	306
1933–35							
Current prices	5.10***	0.52***	–0.36***	0.42***	–0.24***	0.92	140
Constant prices	5.10***	0.52***	–0.36***	0.42***	–0.28***	0.92	140

Note: Significant at 1% = ***, 5% = ** and 10% = *. White heteroskedasticity-Consistent Standard Errors and Covariance.

Sources: ASEA (1900–1935), the Swedish Royal Library (1900–1935) and own calculations.

5.2 The hedonic price index

Table 6 presents the results of the hedonic price index as the rate of change for each of the adjacent years and as a price index. The main findings are that current and PPI-deflated prices decreased at an average rate of 2.2 and 2.6 percent per year 1900–35.

Table 6: Hedonic price indexes for alternating current slip-ring electric motors in current and PPI-deflated prices in Sweden 1900–35

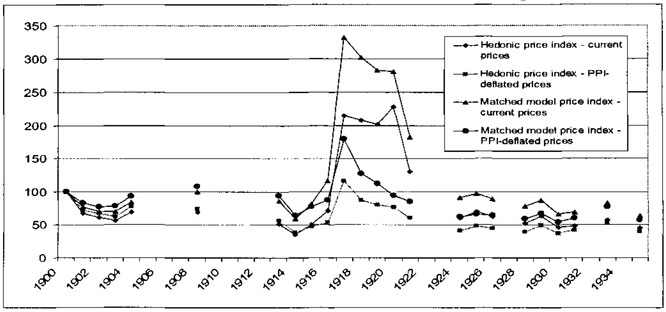
Year	*Rate of change using*		*Index using*	
	Current prices	Constant prices	Current prices	Constant prices
1900	–	–	100	100
1901	–0.33	–0.28	67.4	72.3
1902	–0.09	–0.07	61.2	67.1
1903	–0.08	–0.07	56.2	62.2
1904	0.22	0.23	68.8	76.8
1905–07	–	–	–	–
1908	0.01	–0.03	69.3	74.5
1909–12	–	–	–	–
1913	–0.26	–0.25	51.1	56.1
1914	–0.30	–0.31	35.6	38.6
1915	0.41	0.22	50.1	47.2
1916	0.43	0.13	71.4	53.5
1917	2.01	1.17	214.9	116.1
1918	–0.03	–0.25	207.9	87.3
1919	–0.03	–0.09	201.5	79.8
1920	0.13	–0.04	227.3	76.3
1921	–0.42	–0.21	130.9	60.6
1922–23	–	–	–	–
1924	–0.54	–0.32	60.5	41.3
1925	0.16	0.16	70.0	48.0
1926	–0.11	–0.08	62.0	44.1
1927	–	–	–	–
1928	–0.16	–0.11	52.3	39.2
1929	0.21	0.25	63.5	48.9
1930	–0.28	–0.24	45.9	37.1
1931	0.05	0.13	48.0	42.0
1932	–	–	–	–
1933	0.19	0.27	57.4	53.1
1934	–	–	–	–
1935	–0.21	–0.24	45.2	40.3

Sources: ASEA (1900–1935), the Swedish Royal Library (1900–1935) and own calculations.

However, the price decrease largely depends on which time periods are analyzed. *Figure 2* shows the hedonic price indexes for electric motors in current and PPI-deflated prices (1900=100). Until 1913, prices and characteristics were only observed for a few years.[29] Nonetheless, according to *figure 2*, the hedonic prices decreased substantially during the first years of the 1900s. Prices then increased in 1904 and continued to decrease until 1914.

[29] This means that for the period 1900–13, the estimated coefficients are kept constant for considerably longer time periods than in 1913–35.

Figure 2: Hedonic and matched model price indexes for alternating current slip-ring electric motors 1900–35 in current and PPI-deflated prices (1900=100)



Sources: ASEA (1900–1935), the Swedish Royal Library (1900–1935) and own calculation

During World War I, prices increased substantially, especially in 1917 when the PPI-deflated prices for electric motors increased by 117 percent as compared to 1916. After 1917, the price trend was clearly decreasing. During the period of high productivity growth 1920–29, current prices of electric motors decreased by approximately 13.2 percent per year. The corresponding figure in PPI-deflated prices was 4.8 percent per year in 1920–29. However, there were some years during the 1920s when prices for electric motors increased. For example, hedonic prices increased substantially in 1925 and 1929.[30]

5.3 The matched model price index

Table 7 shows results of the matched model price index and the share of electric motors that were matched for each pair of adjacent years. Current and PPI-deflated prices decreased by 1.3 and 1.6 percent per year in 1900–35. This indicates that prices for electric motors based on the matched model methodology decreased less rapidly than prices based on the hedonic methodology 1900–35.[31] The annual price decrease in current and PPI-deflated prices was 12.2 and 3.7 percent in 1920–29.

[30] One possible explanation for the increase in hedonic prices in 1925 is discussed in section 6.
[31] This is further analyzed in section 6.2.

Table 7: Matched model price indexes for alternating current slip-ring electric motors in current and PPI-deflated prices in Sweden 1900–35

Year	Rate of change using		Index using		Percentage matched
	Current prices	Constant prices	Current prices	Constant prices	
1900	–	–	100	100	–
1901	–0.23	–0.17	77.2	82.8	13
1902	–0.09	–0.07	70.1	76.9	100
1903	0.002	0.01	70.2	77.7	26
1904	0.20	0.20	84.0	93.7	11
1905–07	–	–	–	–	–
1908	0.20	0.15	100.4	107.9	22
1909–12	–	–	–	–	–
1913	–0.14	–0.12	86.3	94.7	23
1914	–0.32	–0.33	58.8	63.8	30
1915	0.39	0.21	81.7	77.1	34
1916	0.42	0.13	116.1	87.1	11
1917	1.86	1.07	332.4	180.0	9
1918	–0.09	–0.29	301.6	126.9	21
1919	–0.06	–0.12	282.5	112.1	59
1920	–0.005	–0.16	281.1	94.5	33
1921	–0.35	–0.10	182.8	84.8	38
1922–23	–	–	–	–	–
1924	–0.50	–0.27	91.2	62.3	19
1925	0.06	0.07	96.8	66.5	26
1926	–0.07	–0.04	89.6	63.9	29
1927	–	–	–	–	–
1928	–0.12	–0.07	78.7	59.1	35
1929	0.11	0.14	87.1	67.2	27
1930	–0.24	–0.20	66.6	53.9	22
1931	0.03	0.12	68.9	60.3	27
1932	–	–	–	–	–
1933	0.21	0.28	83.4	77.3	16
1934	–	–	–	–	–
1935	–0.23	–0.26	64.0	57.2	9

Sources: ASEA (1900–1935), the Swedish Royal Library (1900–1935) and own calculations.

The share of electric motors that was matched varies between 9 and 100 percent, depending on the period analyzed. The average matching ratio was 27.7 percent in 1900–35. For the years 1901–02, 100 percent of the electric motors were matched. The price decrease was 9 percent in current prices and 7 percent in PPI-deflated prices. Exactly the same results are obtained by the hedonic price indexes 1901–02 (see *table 6*). This confirms the well known fact that hedonic and matched model price indexes produce identical results when 100 percent of the observations are matched.

6. Analyzing and comparing different price indexes

In this section, the three questions posed in the introduction are analyzed in detail by using the results presented in section 5.

6.1 Productivity in the electric motor producing industry

Kendrick (1961) estimates US labor productivity growth 1919–29 for Electric machinery to only have been 4.1 percent per year. This was below the average annual labor productivity growth rate of 5.1 percent in US manufacturing. The results presented in this paper suggest that electric motor prices in Sweden decreased substantially in 1920–29. The results are similar notwithstanding if hedonic or matched model price indexes are used. According to the hedonic price index, the annual price decrease was 13.2 percent, while it was 12.2 percent according to the matched model price index. In PPI-deflated prices the annual price decrease was 4.8 and 3.7 percent, based on hedonic and matched model price indexes. This indicates that prices decreased considerably more for electric motors as compared to total manufacturing.

No matter which type of index is being used, it is evident that prices for electric motors decreased substantially in Sweden during the 1920s. Rapidly decreasing prices constitute a good indication of productivity growth, as long as competition remains unchanged. Thus, it becomes very important to try to analyze whether competition remained reasonably constant in the Swedish market for electric motors 1900–35. There are no data available to test the market structure of the electric motor industry. However, it is possible to use results from qualitative research on the electric motor industry.

Glete (1983) documents the history of ASEA 1883–1983. ASEA was one of the largest producers of electric motors in Sweden 1900–35.[32] According to Glete, there was very strong competition in the market for electric motors until 1925. Many new companies began to produce standardized electric motors in 1900–24 and competition was fierce.

[32] Glete (1983) also includes an overview of the other companies included in this investigation.

But in 1925, a cartel was formed between the major producers of electric motors. The companies participating in the cartel were: ASEA, Luth&Rosén, Elektromekano, AEG and Siemens. However, the cartel was not very strong and only functioned upon mutual agreement among all these companies (Glete 1983). The cartel could be one of the reasons why prices of electric motors increased rapidly in 1924–25. This price increase is indicated in the hedonic price index where PPI-deflated prices increased by 16.2 percent, but less strongly in the matched model price index, where the increase was 6.7 percent.

Figure 2 shows that the cartel did not have a very strong effect over a longer time period, since the trend in prices of electric motors continued to decrease after 1925. Results from qualitative sources thereby support the view that rapidly decreasing prices reflect increases in productivity. Even though there might have been less competition among electric motor manufacturers after 1925, prices continued to decrease which is a strong indication of productivity growth.

Table 8 presents figures of labor productivity growth in Swedish Electric machinery in 1913–35. Labor productivity has been defined as the production value per person employed.[33] The hedonic and matched model price indexes estimated in this paper have been used to calculate production value in constant prices.[34]

Table 8: Annual Labor productivity growth in Electric machinery in Sweden 1913–35 (percent)

Year	*Growth rate*	
	Hedonic deflation	Matched model deflation
1913–1919	–7.2	–4.2
1920–1929	12.1	10.8
1930–1935	–2.5	–2.0
1913–1935	3.0	3.8

Note: Labor productivity is defined as production value per person employed.

Source: Kommerskollegium (1900–35) and own calculations

[33] Unfortunately, it has not been possible to calculate labor productivity based on value added, which implies that only single deflation is used to calculate productivity.
[34] It is only the price index for slip-ring electric motors with 1–100 horsepower that has been used to calculate production value in constant prices for Electric machinery. Thereby, it is assumed that other electric motors would have a similar price development.

Table 8 shows annual labor productivity growth in Swedish Electric machinery 1920–29 to have been 12.1 percent with hedonic deflators and 10.8 percent with matched model deflators. Thereby, there is strong evidence of productivity growth in the electric motor producing industry having been very high during the 1920s. However, it is still a puzzle why productivity did not increase more in US Electric machinery during the 1920s.

6.2 Comparing hedonic and matched model price indexes

Figure 2 compares the hedonic price index with the matched model price index for current and PPI-deflated prices, respectively. For the whole period 1900–35, the hedonic price index is lower than the matched model price index for current as well as PPI-deflated prices. For the period 1900–35, the PPI-deflated hedonic price index decreased by 2.6 percent per year, while the corresponding figure was 1.6 percent for the matched model price index. The annual difference is thus approximately 1 percentage point between the two price indexes in 1900–35. In 1920–29, the PPI-deflated hedonic and matched model price indexes decreased by 4.8 and 3.7 percent per year, respectively. Thus, the difference was 1.1 percentage points.

For some years, the hedonic and matched model price indexes for electric motors produce very different results. However, on average, the difference between the two indexes was not larger than 1 percentage point. One possible explanation why matched model and hedonic price indexes differ is that prices of non-identical products are matched. In this paper, I have tried to use similar requirements for matched model and hedonic price indexes. Nevertheless, it was not possible to match electric motors without allowing some variation of characteristics. This might be one of the reasons why hedonic and matched model price indexes differ. Another explanation is that price changes of matched models are not representative of price changes of unmatched models. However, hedonic and matched model price indexes produce similar results for many years, even when the share of matched models is low. Thus, there is no clear evidence that the hedonic and matched model price indexes would differ more for years with low shares of matched models as compared to years with high shares.

6.3 Comparing the electric motor with the computer

The last question to be addressed is whether the price decrease of electric motors estimated by hedonic and matched model price indexes can challenge the rapidly decreasing prices for ICT-products, such as computers. Berndt & Rappaport (2001) use hedonic regressions based on three continuous characteristics to measure the price change in desktop computers and mobile computers 1976–99. Their regression model was kept simple to facilitate comparability and feasibility over a quarter-century time frame in the dynamic PC market. The three continuous characteristics are hard-disk memory in MB, processor speed in MHz and the amount of RAM in MB. They also include indicator variables for whether the model included a CD-ROM, if it was an Apple brand, an IBM-compatible computer or any other brand. Moreover, they allow parameters for characteristics to vary annually and thereby permit a relatively unrestrictive impact of changes in characteristics on prices.[35]

Table 9 presents Berndt & Rappaport's results for the price change for desktop and mobile computers in the US in 1976–99. The results are presented both for the Laspeyres index formula and the Paasche index formula. If the Laspeyres formula is used, desktop prices on average decreased by 30.1 percent per year in 1976–99, while the prices of mobile computers decreased by 26.0 percent per year in 1983–99. The results differ by less than 1 percentage point per year if the Paasche index formula is substituted for the Laspeyres index. It is also interesting to note that the price decrease accelerated in 1994–99.

If the price development of electric motors is compared to that of computers, it is clear that the prices of electric motors decreased much more slowly than the prices of computers over a 25-year period, when the hedonic methodology is used. There are some years when the hedonic prices of electric motors decreased by more than 30 percent per year, but these years were followed by increases in electric motor prices. It also appears that prices of the electric motor were much more volatile as compared to those of the

[35] One limitation in the data set used by Berndt and Rappaport is that the 1982–88 data contain transaction prices, while the data for 1976–81 and 1989–99 incorporate list prices. Moreover, for 1976–81 and 1993–99, they do not have access to quantity sales data, which implies that all models are weighted equally in their price indexes.

computer. It is possible that one of the reasons for the high volatility was the effects of World War I.

Table 9: Average annual price change for desktop and mobile computers in the US 1976–1999 based on hedonic price indexes

Year	*Laspeyres*		*Paasche*	
	Desktop	Mobile	Desktop	Mobile
1976–83	–23.2	n.a.	–21.8	n.a.
1983–89	–24.8	–15.8	–24.6	–15.8
1989–94	–34.5	–19.4	–30.2	–18.0
1994–99	–40.0	–41.8	–42.2	–41.2
1976–99	–30.1	n.a.	–29.2	n.a.
1983–99	–32.9	–26.0	–32.2	–25.3

Note: n.a indicates not available. The results are based on merged adjacent-year and yearly models.

Source: Berndt & Rappaport (2001).

Table 10 presents the average price change for different ICT-products based on hedonic and matched model price indexes for different countries and time periods. According to *table 10*, prices decreased more for all ICT-products, except TVs in Japan, when the hedonic method was used instead of the matched model. The difference in percentage points between the matched model and hedonic estimates varies considerably. For computers in France, the average difference was 28.4 percentage points, while it was only 2.4 for PCs in Japan.

Table 10: Annual price change for ICT-products based on hedonic and matched model price indexes for different time periods and countries

Country	*Period*	*Product*	*Matched model*	*Hedonic index*	*Difference*
Netherlands	Jan 1999 – Jan 2002	PCs	–21.9	–32.5	10.6
Netherlands	Jan 1999 – Jan 2002	Notebooks	–20.5	–25.5	5.0
Netherlands	Jan 1999 – Jan 2002	Servers	–22.1	–27.3	5.2
France	2001-I – 2002-II	Computers	–13.7	–42.1	28.4
Japan	1995-I–1999-I	PCs	–42.7	–45.1	2.4
Japan	1995-I–1999-I	TVs	–18.8	–10.4	–8.4
Australia	Apr 2000–Dec 2001	PCs	–32	–52	20.0
USA	1972–1984	Computer processors	–8.5	–19.5	11
USA	1989–1992	Desktop PCs	–19.3	–31.2	11.9

Note: The hedonic price index is based on the dummy variable method for all countries, except France where the hedonic imputation method has been used.

Sources: Triplett (2004) and Berndt, Griliches & Rappaport (1995).

For electric motor prices, the difference between hedonic and matched model price indexes was 1 percentage point per year in 1900–35. One possible reason why the difference between the matched model and hedonic price indexes is larger for computers as compared to electric motors, is that a considerably larger number of new models of computers were introduced. For example, the data set used by Berndt & Rappaport (2001) consisted of 9 mobile models in 1983 and 1165 models in 1999. When new models are introduced, they can often not be matched, but still affect the hedonic index. Hence, price changes of matched models are not representative of price changes of unmatched models.

To sum up, during the 1920s, the hedonic and the matched model price estimates decreased by 13.2 percent and 12.2 percent per year for electric motors in Sweden. Labor productivity growth 1920–29 becomes 12.1 percent per year if hedonic price estimates are used to calculate production value in constant prices. This suggests that there was high productivity growth in the industry producing electric motors during the 1920s. For computers and ICT equipment, prices decreased by more than 30 percent per year 1976–99. The results presented in *table 9* suggest that prices for computers decreased more than 3 times as rapidly 1994–99 compared to electric motors 1920–29. Thereby, it is evident that the price decrease of electric motors cannot challenge the price decrease of computers and other ICT-products, even if the hedonic methodology is applied to historical price data. This supports the findings by Jovanovic & Rousseau (2005) that ICT seems to be technologically more revolutionary as compared to electricity.

7. Conclusions

Productivity is a crucial measure of the impact of major technological breakthroughs. To correctly estimate productivity over time, it is necessary to have accurate price indexes. One of the major problems with constructing price indexes is to adjust for quality change. During the 1990s, many statistical agencies began to use hedonic price indexes to adjust for the rapid quality change in ICT-products (van Mulligen 2003). But since hedonic price indexes had not previously been used, it is very difficult to compare estimates of productivity growth at the industry level for the ICT revolution and previous breakthroughs. In this study, hedonic price indexes are used also for electric equipment during the electrification in order to assess how that would affect prices and productivity.

A major effort was made to collect data on prices and characteristics for electric motors in Sweden 1900–35. These prices and characteristics were used to construct hedonic and matched model price indexes for electric motors. The estimated hedonic price indexes indicate that electric motor prices decreased at an annual rate of 2.2 and 2.6 percent in current and PPI-deflated prices, respectively, in 1900–35. The corresponding figures for the matched model price index were 1.3 and 1.6 percent per year. During the 1920s, the hedonic and the matched model price change estimates decreased by 13.2 and 12.2 percent per year. The annual PPI-deflated price decrease in 1920–29 was 4.8 and 3.7 percent for hedonic and matched model price indexes, respectively.

No matter which type of index is being used, it is evident that prices for electric motors decreased substantially in Sweden during the 1920s. This indicates a high productivity growth in the electric motor industry in 1920–29. In 1925, a cartel was formed by companies manufacturing standardized electric motors. However, the cartel only had a temporary impact on the price of electric motors. After a one-off price increase in 1925, the trend in prices continued to be downward.

Using hedonic price indexes to deflate the production value of Swedish Electric machinery, annual labor productivity growth 1920–29 was estimated to be 12.1 percent.[36] For the period 1919–29, annual labor productivity growth in US manufacturing was 5.1 percent, while labor productivity growth in Electric machinery was 4.1 percent per year. The analysis in this paper suggests that productivity growth in the US Electric machinery industry would increase if hedonic and matched model price indexes were used also to deflate prices in US Electric machinery. However, there are also other potential explanations. For example, the US productivity figures are based on value added, while

[36] The corresponding figure for the matched model price index is 10.8 percent per year (see *table 8*).

the Swedish ones are based on production value. Value added price deflators may differ considerably from production value price deflators (Edquist 2005) since value added price deflators also depend on the price changes of inputs and the relation between value added and production value.[37]

This paper has also investigated whether price changes for electric motors differ substantially, depending on whether hedonic or matched model price indexes are used. The results show that hedonic price indexes decreased by 1 percentage point more per year than the matched model price indexes for 1900–35. For the period 1920–29, the annual difference was also 1 percentage point. The results indicate that the differences between the hedonic and matched model price indexes are not very large over a considerable time period. Nonetheless, on a year-to-year basis, the differences between the two price indexes can be large.

The price changes for electric motors 1900–35 were also compared with those for ICT-products 1976–99. The results clearly showed that, over a longer time period, hedonic prices decreased considerably more rapidly for computers as compared to electric motors. According to Berndt & Rappaport (2001), the hedonic price change for desktop computers on average decreased by 30.1 percent per year 1976–99. The annual price decrease for electric motors, estimated by hedonic price indexes, was 2.2 percent in 1900–35 and 13.2 percent in 1920–29. The conclusion is that over a longer period of time, electric motor prices did not decrease as much as computer prices, even if hedonic price methods are used for electric motors.

The results also show that the hedonic and the matched model price indexes differ considerably more for ICT-products than for electric motors. One explanation for this could be that a considerably larger number of new models were introduced for computers than for electric motors. When new models are introduced they can often not be matched, but affect the hedonic price index. Finally, the results show that the price decrease of

[37] Another explanation for the different productivity results for US and Swedish Electric machinery might be that Swedish Electric machinery was simply more productive than that in the US. Moreover, it is also possible that the price decrease of other electric motor models was less rapid than for the electric motors used in this study.

electric motors cannot rival the price decrease of computers and other ICT-products, even if the hedonic methodology is applied to historical price data.

8. Appendix

Appendix A: Hedonic price indexes

Suppose $\hat{B}^1$ to be the estimated coefficient of the D^1 time dummy variable in equation (1). The coefficient $\hat{B}^1$ in equation (1) is an estimate of the price index between period t and $t+1$. For a hedonic function with a logarithmic dependent variable, the formula for the dummy variable index is:

$$index\{(t+1)/t\} = \exp(\hat{B}^1) = \left[\frac{\prod_{i=1}^{I} (p_{i,t+1})^{1/n}}{\prod_{i=1}^{I} (p_{i,t})^{1/m}} \right] \div [HQA]^{\cdot} \tag{4}$$

The dummy variable index equals the ratio of an unweighted geometric mean of prices in periods t and $t+1$, divided by a hedonic quality adjustment (HQA). In the usual case, hedonic regressions are run on unbalanced samples, so that the number of observations may differ in the two periods as indicated by subscripts m and n.

The hedonic quality adjustment depends on the form of the hedonic function. For the double-log hedonic function, the hedonic quality adjustment is given by:

$$HQA = \exp\left[\sum_{k=1}^{K} \hat{a}_k \left(\left(\sum_{k=1}^{K} z_{ik}^{t+1} / n \right) - \left(\sum_{k=1}^{K} z_{ik}^{t} / m \right) \right) \right]. \tag{5}$$

Equation (5) is a quantity index measuring the change in characteristics of electric motors sold in periods t and $t+1$. The terms in square brackets are the mean change in characteristics between periods t and $t+1$. The changes in characteristics are valued by their implicit prices, which are the $\hat{a}_k$ coefficients from the hedonic function (see equation 1).

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PAPER 3

Parallel Development? Productivity Growth Following Electrification and the ICT Revolution*

Harald Edquist

Abstract

This paper investigates labor productivity growth and the contribution to labor productivity growth in Swedish manufacturing during electrification and the ICT revolution. The paper distinguishes between technology-producing, intensive and less intensive technology-using industries during these technological breakthroughs. The results show that labor productivity growth and the overall contribution to labor productivity growth was considerably higher in technology-producing industries following the ICT revolution. On the other hand, the relative contribution to aggregate labor productivity growth was considerably higher in intensive technology-using manufacturing industries following electrification.

JEL Classification: N64, O33, O47

Keywords: Electrification, ICT revolution, Productivity growth, Technological change

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1. Introduction

Since the eve of the industrial revolution, there has been a number of major technological breakthroughs. Steam, electricity, internal combustion and information and communication technology (ICT) are only a few examples. One way of distinguishing revolutionary technologies from less important technologies is to use the General Purpose Technology (GPT) concept. According to the GPT framework, whole eras of technical progress are driven by a few GPTs, characterized by pervasiveness, inherent potential for technical improvements and innovational complementarities giving rise to increasing returns to scale (Bresnahan & Trajtenberg 1995).[1] A number of studies have compared the impacts of different GPTs (see, for example, David 1990; 1991; Gordon 2000; Crafts 2004; Jovanovic & Rousseau 2005; Edquist & Henrekson 2006). Most of these studies have focused on the development in the British or US economy. This paper will compare two GPTs in Sweden, namely electrification and the information and communication technology (ICT) revolution.

Several studies have argued that the increased use of electric motors in manufacturing had an important, but delayed effect on productivity growth (Devine 1983; David 1990; 1991). The impact of ICT on productivity growth has been debated over the last decades. For a long time, there was little evidence that the use of computers and other ICT equipment had any significant impact on productivity growth.[2] However, since the post 1995 increase in productivity growth in the US economy, there is evidence of increased use of ICT having had positive effects on productivity growth. Several firm-level studies suggest ICT use to have a large economic impact (Brynjolfsson & Hitt 2000). Nonetheless, there are also studies that are more skeptical towards the economic impact of ICT across industries. Gordon (2000) argues that the revival in productivity growth primarily occurred within durable goods production, particularly in ICT-producing

[1] There are also other theoretical approaches for analyzing major technological breakthroughs; see, for example, Freeman & Soete (1987).
[2] This paradox has been named the Solow Paradox after Nobel Laureate Robert Solow's statement: "You can see the computer age everywhere but in the productivity statistics" (Solow 1987, p. 36).

industries. He suggests that the effects of ICT have not been far reaching, but rather concentrated to a few industries of the economy.

A new perspective of the impact of ICT has been to investigate the impact on productivity growth by ICT-producing, intensive ICT-using and less intensive ICT-using industries.[3] According to Stiroh (2002), industries that made the largest ICT investments in the 1980s and early 1990s have had larger productivity gains after 1995. Stiroh also provides a decomposition of aggregate productivity growth into the contribution of individual industries. The results show that ICT-producing and ICT-intensive using industries accounted for approximately 80 percent of productivity growth in the US economy 1995–2000. Moreover, these industries also accounted for all the direct industry contributions to the US acceleration in productivity growth in 1995–2000, as compared to 1987–1995. A similar framework is used by van Ark *et al.* (2003) to show that the key differences in productivity growth between Europe and the US are in intensive ICT-using services.

The findings by Stiroh (2002) and van Ark *et al.* (2003) raise questions about how important technology-producing, intensive and less intensive technology-using industries were for earlier GPTs. By comparing the impacts of electrification and ICT in the US, Jovanovic & Rousseau (2005) find that electrification was more broadly adopted, while ICT seems to be more technologically revolutionary. However, Jovanovic and Rousseau do not investigate the impact of industries using the new technology more intensely during the two breakthroughs. To my knowledge, no one has investigated the contribution of intensive technology-using industries to labor productivity growth following earlier technological breakthroughs. The primary purpose of this paper is therefore to use the framework provided by Stiroh (2002) and van Ark *et al.* (2003) to compare the contribution to labor productivity growth by technology-producing, intensive and less intensive technology-using industries following two GPTs, namely electrification and ICT. The object of study is Swedish manufacturing.

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[3] These industries are defined according to Stiroh (2002) and van Ark *et al.* (2003) and discussed in section 2.2.1.

The paper consists of two parts. The first part provides a short overview of electrification and the ICT revolution in Sweden. In particular, the diffusion of new technology in manufacturing will be emphasized. The second part uses decomposition methods to investigate the contribution of technology-producing, intensive and less intensive technology-using industries on labor productivity growth during electrification and the ICT revolution. More specifically, the following questions will be addressed:

- How long did it take until the new technology was adopted in Swedish manufacturing during each breakthrough?
- When did labor productivity start to increase in Swedish manufacturing following the introduction of the new GPTs?
- How much did manufacturing industries classified as producers, intensive and less intensive users of the new technology contribute to labor productivity growth following electrification and the ICT revolution in Swedish manufacturing?[4]

To answer these questions, data have been collected from a number of different sources. Section 2 describes the data and methods used. Section 3 provides a short overview of the diffusion of new technology during electrification and the ICT revolution. Section 4 investigates the contribution to labor productivity growth from technology-producing, intensive and less intensive technology-using industries. Section 5 concludes.

2. Data and method

2.1 Time periods and Data

2.1.1 Time periods

According to Gordon (2006) the 1920s and 1990s featured an explosion of applications of a fundamental "General Purpose Technology" in the US. Moreover, both decades experienced productivity growth acceleration and the accompanying booms of

[4] This article does not investigate whether investments in new technology actually resulted in higher productivity growth. Instead, a comparative perspective is used to investigate whether there is a major difference in productivity growth patterns in technology-producing, intensive and less intensive technology-using industries following electrification and the ICT revolution.

investments. The investigation of electrification in Sweden will focus on the contribution to labor productivity growth in the interwar period 1920–39. The reason for this is to avoid the effects of World Wars I and II on the Swedish economy. The period 1920–39 will be divided into subperiods 1920–30 and 1930–39, which implies that productivity is measured from peak-to-peak over the business cycle.[5] According to Field (2003), choosing business cycle peaks for beginning and end points largely controls for the variations in capacity utilization that occur over the business cycle. The productivity analysis for the ICT revolution will be carried out for the period 1993–2003.[6] According to Statistics Sweden (2005), 1993 was at the bottom of the Swedish business cycle and the period 2001–2003 were years when GDP growth slowed down compared to growth rates in the late 1990s.

2.1.2 Data on electrification

The data that are used to analyze electrification in Swedish manufacturing are based on primary data collected from the Swedish Official Statistics (Kommerskollegium 1906–1939) and the Swedish Statistical Yearbook (1922–42). The data include figures of primary power capacity in Swedish manufacturing at a very detailed industry level.[7]

In addition to primary power, the data also include the total capacity of electric motors used in manufacturing and the capacity of "driving generators", i.e. prime movers involved in generating electricity.[8] This makes it possible to distinguish between the primary capacity used for direct drive and the primary capacity used to produce electricity.[9] By dividing the capacity of electric motors by the sum of the capacity of prime movers used for direct drive and electric motors, a measure of the capacity of

[5] According to Edvinsson (2005), 1920, 1930 and 1939 were years when the business cycle peaked in Sweden.
[6] Due to the industry classification SNA 93–ENA 95, comparable output and labor input data are only available at the 2-digit ISIC level in 1993–2003.
[7] Primary power is the power produced by prime movers that utilize the potential energy of nature and directly convert it into energy of motion (Du Boff 1979).
[8] In this paper, power capacity is measured in horsepower, where one unit is equivalent to a rate of 550 foot-pounds per second.
[9] Those machines run directly by installed prime movers are said to be powered by direct drive.

electric motors used in total mechanical drive is obtained. This measure provides a very good indication of the intensity of electric motors used in each industry.[10]

The Swedish Official Statistics started to report the capacity of electric motors used in manufacturing in 1906.[11] In 1913, a major revision of the Swedish industry classification system was implemented. One major change in the classification of 1913 was the exclusion of firms with less than ten employees (see appendix A). This implies that the aggregate figures for the period 1906–1912 are not fully comparable with the figures for the period 1913–1939. Therefore, data for the period 1906–1939 will only be used to describe the process of electrification for aggregate manufacturing.[12]

Productivity estimates for manufacturing during electrification are based on data of production value and the number of persons employed provided by Kommerskollegium (1920–1939). Price indexes and industry classification are based on Ljungberg (1990).[13] The industry classification includes 32 industries – see *table 2*.[14] Mining and Power lightning and waterworks are not considered to belong to manufacturing and are therefore excluded.[15]

The method used to calculate the contribution of each industry to labor productivity growth requires data on labor compensation (see section 2.2.3). Labor compensation during electrification has been estimated using data on wages and the number of person employed at the industry level. These data are based on the Swedish Statistical Yearbook

[10] This measure of electric motor intensity cannot be used for the US economy before 1939. The reason is that there are no estimates of driving generators available for this period (Du Boff 1979). The US data distinguish between primary electric motors and secondary electric motors. Primary electric motors are driven by electricity purchased from utilities outside the manufacturing plant, secondary electric motors are driven by electricity from generators and prime movers within the plant itself. However, the relationship between secondary electric motors and driving generator is difficult to establish and can vary between different industries (Du Boff 1979).
[11] The capacity of electric motors was also reported in 1896, but not for the period 1896–1905.
[12] The choice of 1939 as the end year for the investigation is due to the outbreak of World War II and the fact that approximately 90 percent of Swedish manufacturing had been electrified by then.
[13] The data for production value and electric motor capacity were available at even less aggregated industry levels, but production value in fixed prices could not be estimated for these industry levels.
[14] There were no price indexes available for Furniture and fixtures and Converted paper products. Hence, it has not been possible to estimate productivity for these industries and therefore, they have been excluded in *table 2*.
[15] These industries are excluded because they are not included in manufacturing in 1993–2003.

(1922–42) and Kommerskollegium (1920–39). For a detailed description of the sources and underlying assumptions used to estimate labor compensation, see appendix B.

2.1.3 Data on ICT

It has been more difficult to find data on the diffusion of ICT than on the diffusion of electric motors. One reason for this is that Statistics Sweden did not conduct any major surveys of the diffusion of ICT in Swedish manufacturing until 2000. The only data available are the ICT capital stock. However, they are only available at a very aggregate level (see section 3.2). Thus, there is a lack of ICT technology data in Swedish manufacturing in 1980–1999. However, for the period 2000–2004, it has been possible to find data on ICT diffusion in manufacturing. These data are based on surveys that Statistics Sweden started to conduct in 2000.

Data on labor productivity during the ICT revolution are based on the official Swedish national accounts (Statistics Sweden 2005) which include figures on value added, production value, number of persons engaged and labor compensation at the 2-digit ISIC level in 1993–2003.[16] The national accounts include figures of both manufacturing and services. One major problem with comparing the productivity development during electrification and the ICT revolution is that there are no productivity estimates available for the service sector during electrification. Moreover, the productivity estimates for services are also very uncertain for the ICT revolution due to measurement problems. Therefore, services will only be included to show that the main results of the productivity development during the ICT revolution are robust also when service industries are included (see section 4.3).

2.2 Method

2.2.1 Classification of technology intensive industries

To distinguish between industries that were using electric motors more or less intensely during electrification, a similar method as that proposed by Stiroh (2002) and van Ark *et*

[16] ISIC stands for International Standard for Industry Classification. Value added in fixed prices for the Radio, television and communication equipment (RTC) industry is only available in 1993–2001.

al. (2003) will be used. Stiroh uses the flow of capital services from ICT as a share of total capital services.[17] Then, he defines the ICT-intensive industries as the industries with an above median value of the 1995 ICT share of capital services. The industries with below median value are defined as less intensive ICT-using industries. The definition of ICT-producing industries is based on OECD (2002).[18]

There are no estimations of the flow for capital services available during electrification in Sweden. Therefore, the industries with an above median value of the electric motor capacity as a share of total mechanical drive capacity will be defined as intensive users of electric motors. Thus, the measure is a proxy for how much of the total machinery stock that had been electrified at different time periods. The average ratio of electric motors and total capacity in mechanical drive in 1920–39 is used to calculate electric motor intensity. Moreover, the only industry producing electric equipment was Electric machinery and cables. Therefore, it will be defined as the electric motor equipment producing industry.

There are also other possible measures that could be used to measure the intensity of electric motors used in production. It could be argued that electric motors saved energy and that it was therefore possible to increase the power capacity per employee. Hence, electric motor capacity per employee could be another way of measuring electric motor intensity. Why then is electric motor capacity as a share of total mechanical drive capacity to be preferred to other measures? According to David (1991) and Devine (1983), the most important reasons why the introduction of electric motors resulted in productivity gains were:

[17] Capital services are the flow of services from the stock of capital. The flows of the quantity of capital services are not usually directly observable and therefore must be approximated by assuming service flows to be in proportion to the stock of assets after each vintage has been converted into standard efficiency units. This is done using age efficiency units because older assets are usually less efficient than newer ones (see OECD 2001).

[18] OECD (2002) defines the following manufacturing industries as ICT-producing: Office accounting and computing machinery (ISIC 30), Insulated wire and cable (ISIC 313), Radio, television and communication equipment (ISIC 32), Instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment (ISIC 3312). Industrial process control equipment (ISIC 3313). In this article, ISIC 30–33 are defined as ICT-producing industries. This is due to the lack of reliable data at less aggregated industry levels than the 2-digit ISIC level in Swedish manufacturing.

- Reduced labor requirements for oiling and maintaining the old drive apparatus.
- Better utilization of labor and materials through rationalization, which was made possible due to the greater flexibility of factory lay-outs when the latter were freed from the constraints formerly imposed by the requirement of orthogonal placement of drive-shafts and machinery.
- Improved machine control leading to increases in output and quality, which was achieved by eliminating the problems of belt slippage.
- Savings in fixed capital through lighter factory constructions.
- Decreased losses since the entire power system did not have to be shut down to carry out maintenance and replacement of some of the machinery.

According to David (1991) and Devine (1983), productivity started to increase primarily because the old machinery was replaced by electric motors. Thus, it was not that each worker got access to more power capacity, but rather the flexibility of electric motors that resulted in increased productivity growth. Therefore, it is necessary to use a measure taking into account how far the replacement process of old equipment had proceeded within different industries to define electric motor intensity.

It is always difficult to establish an exact breaking point for which industries should be classified as intensive electric motor using industries. Therefore, the method favored by Stiroh (2002) will be used, i.e. industries with an above median value of the electric motor capacity as a share of total mechanical drive capacity. This implies that some industries will be classified in different industry groups, even though the difference in electric motor intensity between them is very small (see section 3.3).

2.2.2 Problems with measuring power in manufacturing

Section 2.1.2 explained how power capacity would be used to describe the process of electrification in Swedish manufacturing and define which industries were intensive users of electric motors. Nevertheless, there is one major problem with using capacity data to analyze electrification. Horsepower capacity does not necessarily reflect the work output, i.e. the amount of useful work actually done by a prime mover or electric motor.

It is likely that the full capacity of electric motors or other prime movers was never utilized. Moreover, the rates of capacity utilization vary between different power sources. According to Du Boff (1979), the capacity utilization of electric motors was lower as compared to steam engines. The decentralization process following electrification meant that a few steam engines would be replaced by tens or hundreds of electric motors, each powering an individual machine. It is likely that the combined power capacity of these motors would be greater than the steam power they replaced. Hence, capacity would increase, while the horsepower work output would remain the same. However, estimates by Du Boff (1979) show that these effects were decreasing as the utilization of electric motors increased over time, due to better organization of the production process.

It is important to be aware of the caveats associated with the use of power capacity to analyze electrification. Still, since there are no data available on work output during electrification, data on power capacity remain the best estimates available to analyze the electrification process over time.

2.2.3 Industry contribution to aggregate productivity growth

There are a number of different methods available for measuring the contribution of each industry to aggregate productivity growth (see van Ark *et al.* 2003; Stiroh 2002; OECD 2001). Here, the method recommended by OECD (2001) is used.[19] Labor productivity, *LP* for industry *i* is given by the relation:

$$\frac{d \ln LP_i}{dt} = \frac{d \ln VA_i}{dt} - \frac{d \ln L_i}{dt}, \qquad (1)$$

where $\hat{VA}_i$ is the rate of change of real value added in industry *i* and $\hat{L}_i$ is the rate of change of labor input.

[19] The reason for using the method recommended by the OECD (2001) is that it has been possible to obtain the required data for this method. The method used by Stiroh (2002) requires data on intermediate inputs which are not available in 1920–39.

The aggregate rate of change in value added is a share of the weighted average of the industry-specific rate of change of value added, where weights reflect the current price share of each industry in output (OECD 2001). Thus, if n is the total number of industries:

$$\frac{d\ln VA}{dt}=\sum_{i=1}^{n} s_i^{VA}\frac{d\ln VA_i}{dt}, \quad \text{where } s_i^{VA}=\frac{P_i^{VA}VA_i}{P^{VA}VA} \text{ and } P^{VA}VA=\sum_{i=1}^{n}P_i^{VA}VA_i, \qquad (2)$$

where $P_i^{VA}VA_i$ denotes the current price (index) of value added for industry i, composed of a price index P_i^{VA} and a quantity index VA_i.

The aggregation of industry-level labor input is achieved by weighting the growth rates of labor input by industry with each industry's share in total labor compensation.[20]

$$\frac{d\ln L}{dt}=\sum_{i=1}^{n} s_i^{L}\frac{d\ln L_i}{dt}, \quad \text{where } s_i^{L}=\frac{w_iL_i}{wL} \text{ and } wL=\sum_{i=1}^{n}w_iL_i \qquad (3)$$

where w_i is labor compensation in industry i.

It then follows that aggregate labor productivity growth is defined as the difference between aggregate growth in value added and aggregate growth in labor input,

$$\frac{d\ln LP}{dt}=\sum_{i=1}^{n}(s_i^{VA}\frac{d\ln VA_i}{dt}-s_i^{L}\frac{d\ln L_i}{dt}). \qquad (4)$$

Thereby, the contribution of industry i to aggregate labor productivity growth is $s_i^{VA}\frac{d\ln VA_i}{dt}-s_i^{L}\frac{d\ln L_i}{dt}$ or the difference between its contribution to total value added and total labor input. If $s_i^{VA}=s_i^{L}$, total labor productivity growth is a weighted average of

[20] The estimation of labor input in 1920–39 is described in appendix B.

industry-specific labor productivity growth. Another way of representing equation (4) is by decomposing it into a weighted average of industry-specific productivity growth and a reallocation term R

$$\frac{d\ln LP}{dt}=\sum_{i=1}^{n}s_i^{VA}\left(\frac{d\ln VA_i}{dt}-\frac{d\ln L_i}{dt}\right)+R \text{ where } R=\sum_{i=1}^{n}(s_i^{VA}-s_i^{L})\frac{d\ln L_i}{dt}. \tag{5}$$

The reallocation term R will be positive if an expanding industry (i.e. an industry with an increase in labor input) holds a share in output exceeding its share in labor compensation. This implies that this industry has a higher than average level of labor productivity. A shift of resources to industries with higher levels of productivity implies an increase in aggregate productivity growth (OECD 2001). However, if an expanding industry holds a share in labor compensation exceeding its share in output, the industry has a lower than average level of labor productivity and the shift of resources will then imply a decrease in aggregate productivity growth.[21]

There are no value added data available at the most detailed industry level for the period 1920–39. Therefore, labor productivity estimates during electrification will be based on production value. The use of production value at the industry level implies problems of double counting of intermediary inputs. This means that production value does not only include final output, but double counts those intermediate inputs produced within the industry that are used internally.

As pointed out by Bailey (1986), this problem is very large at the aggregate level, but decreases at the disaggregated industry level. Hence, Bailey (1986) argues that to analyze productivity within manufacturing, it is possible to use either production value or value added. Moreover, to avoid double counting as far as possible, only production value based on the sales values of the final products was used to estimate productivity growth. To make the comparison of productivity growth following the two technological

[21] It is possible that productivity in manufacturing increases because firms with lower than average productivity growth are shut down. If the released employees are then not used in production processes with higher productivity growth, the growth rate of GDP per capita in the total economy will decrease, even though productivity growth in manufacturing increases.

breakthroughs as accurate as possible, production value will also be used to estimate productivity growth following the ICT revolution.[22]

3. Diffusion of electric motors and ICT in manufacturing

3.1 Electrification in manufacturing

Electricity and electric motors were first introduced in Swedish manufacturing during the 1880s. The first users of electricity were the industrial sector and urban households (Kander 2002). In manufacturing, electricity was first used to illuminate factories. But, as the performance of electric motors was improved, they were increasingly used in the manufacturing process (Schön 1990; Norgren 1992). The first electric motors were constructed for direct current. However, as the advantages of transmitting electricity, in the form of alternating current, became evident in the 1890s, the alternating current electric motor came to dominate the market.[23]

In 1896, the capacity of electric motors as a share of total mechanical drive was 2.7 percent.[24] *Figure 1* shows the capacity of electric motors, steam power, water power and gas and petrol engines as a share of the total capacity used for mechanical drive in 1906–1939. According to *figure 1*, the share of electric motor capacity used for mechanical drive increased steadily over time. In 1906, 18.6 percent of the mechanical drive in Swedish manufacturing was performed by electric motors, while the corresponding figure in 1939 was 88.9 percent. Hence, Swedish manufacturing was electrified very rapidly in the early twentieth century. According to Devine (1983), the first electric motors used in production just replaced steam engines and water wheels. A further step was to connect a single electric motor to each machine. This unit drive system resulted in increased

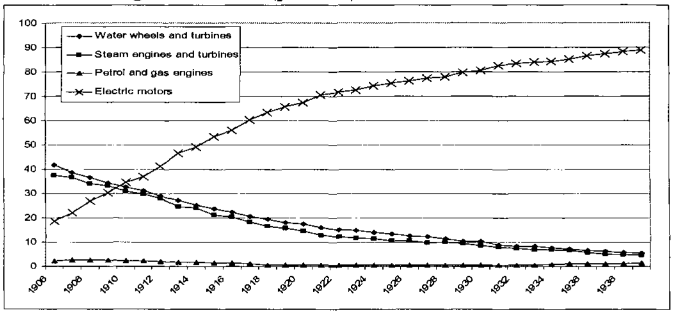
[22] The main productivity growth results are robust when value added is used instead of production value to estimate labor productivity growth in 1993–2001.

[23] The first transmission of electricity in Sweden over a longer distance was carried out between Hellsjön and Grängesberg in 1893 (Hjulström 1940). Nonetheless, it took a long time until more than 50 percent of the mechanical drive had been electrified in Swedish manufacturing.

[24] The first statistics of the capacity of electric motors is from 1896. For the period 1897–1905, the capacity of electric motors was not reported in the official statistics. This implies that consistent figures are only available for the period 1906–1939.

flexibility of the production process. According to Schön (1990), the unit drive system was implemented in most Swedish factories in the 1920s.

Figure 1: Capacity of electric motors, water power, steam power and petrol and gas engines as a share of the total capacity of the mechanical drive in Swedish manufacturing 1906–1939 (percent)



Source: Kommerskollegium (1906–39) and own calculations.

Figure 1 also shows that the relative importance of steam and water power declined considerably. In 1906, 41.6 percent of the mechanical drive in Swedish manufacturing was performed by water power. The corresponding figure for steam power was 37.6 percent. In 1939, the share of water- and steam power in the mechanical drive had fallen to 5.4 and 4.3 percent, respectively. Even though the importance of steam and water power decreased in the mechanical drive, they continued to be important producers of electricity within manufacturing. This was achieved by connecting a dynamo to the steam engine or waterwheel. When prime movers are used to generate electricity, they are called driving generators.

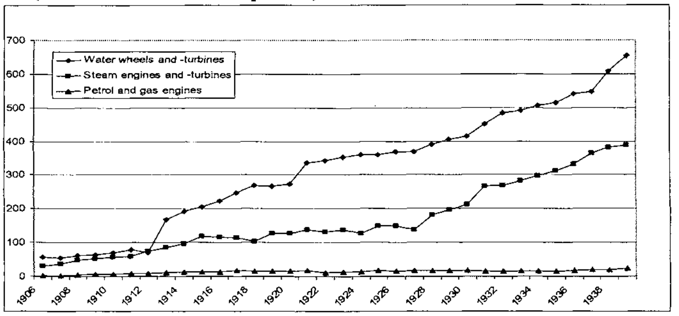
Figure 2 shows the electricity generated by different types of driving generators within manufacturing.[25] According to *figure 2*, the power generated by prime movers within manufacturing increased considerably in 1906–39.[26] Thus, hydroelectric and thermal

[25] In 1906, Swedish official statistics do not distinguish between primary power used for driving generators and mechanical drive for petrol and gas engines. Therefore, it has been assumed that petrol and gas engines had the same share of driving generators and mechanical drive as in 1907.

[26] The change in the methodologies of collecting data for Swedish national accounts seems to have resulted in a sharp increase in the use of hydroelectric power in 1912–13. The reason might be the revision of the Swedish industry classification in 1913 (see appendix A).

power was rapidly transformed from being used in the direct drive into generating electricity.

Figure 2: Capacity generated by driving generators in Swedish manufacturing 1906–39 (in thousands of horsepower)



Source: Kommerskollegium (1906–39) and own calculations.

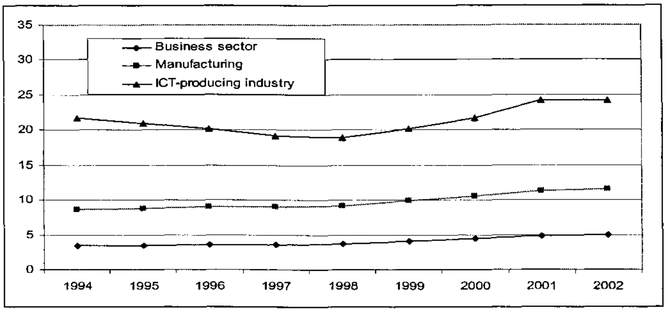
3.2 ICT in manufacturing

In 1947, Bardeen, Brattain and Shockley invented the transistor, which became the basis for numerous electronic innovations. Some examples are the integrated circuit and the microprocessor. Rousseau & Jovanovic (2005) date the arrival of ICT with Intel's invention in 1971 of the "4004" microprocessor. Unfortunately, no considerable amount of data is available on the diffusion of ICT in Swedish manufacturing before the 1990s. Thus, it will be difficult to provide a thorough analysis of the diffusion of ICT in Swedish manufacturing in 1970–2005. Nonetheless, the data available will provide some insights into the diffusion of ICT in Swedish manufacturing.

Figure 3 shows estimates of ICT capital as a share of the total capital stock for the business sector, manufacturing and ICT-producing industries in 1994–2002. According to *figure 3*, the share of ICT capital in manufacturing and the total business sector increased throughout the period. The share of ICT capital increased from 8.6 to 11.6 percent in manufacturing and from 3.4 to 4.9 percent in the business sector in 1994–2002. For ICT-producing industries, the share first decreased from 21.7 to 18.8 percent in 1994–98.

However, it increased from 18.8 to 24.2 percent in 1998–2002.[27] Thus, ICT capital as a share of the total capital stock was at a considerably higher level in the ICT-producing industries as compared to manufacturing and the total business sector.

Figure 3: ICT-capital stock as a share of the Swedish total capital stock for different industries 1994–2002



Note: The following industries are defined as ICT-producing: Office, accounting and computing machinery (ISIC 30), Electric machinery and apparatus (ISIC 31), vision and communication equipment (ISIC 32) and Medical, precision and optical instruments (ISIC 33).

Source: Statistics Sweden (2006).

There are no data available on the use of computers in Swedish enterprises before 2000. The reason for this is that Statistics Sweden did not investigate the use of ICT in Swedish firms before 2000. *Table 1* shows the share of firms and employees using computers and the share of firms with internet access in manufacturing in 2000–05. The share of firms using computers was 96–99 percent in 2000–05. Moreover, in 2003–05, the share of employees working with computers was 63–65 percent, respectively. Finally, the share of manufacturing firms with access to the Internet increased from 89 percent in 2000 to 96 percent in 2005. These figures clearly indicate that by 2000, computers were well integrated in the production process of Swedish manufacturing firms. However, due to lack of earlier data, it is difficult to document how rapid the diffusion process was.

[27] It has not been possible to estimate ICT capital as a share of the capital at more disaggregated levels for other industries than the ICT-producing industry.

Table 1: The share of firms and employees using computers and the share of firms with Internet access in Swedish manufacturing in 2000–2005 (percent)

	2000	*2001*	*2002*	*2003*	*2004*	*2005*
Firms using computers	97 (±1)	98 (±1)	99 (±1)	99 (±1)	98 (±1)	96 (±2)
Employees using computers	n.a	n.a	n.a	63 (±4)	65 (±5)	65 (±4)
Firms with internet access	89 (±2)	96 (±1)	n.a	97 (±2)	97 (±2)	96 (±2)

Note: n.a = not available. Enterprises with less than 10 employees have been excluded in the investigation. Figures in parenthesis show the length of the 95% confidence interval.

Source: Statitsics Sweden (2001–2005).

3.3 Defining industries that were intensive users of new technology

Section 3.1 documented how rapidly Swedish manufacturing was electrified during the first decades of the twentieth century. However, to identify which industries were intensive users of electric motors, it is necessary to also investigate the electrification process at more disaggregated industry levels. Section 2.2.1 defined intensive electric motor using industries as industries with an above median value of the average electric motor capacity as a share of mechanical drive in 1920–39. *Table 2* shows the average electric motor capacity relative to the capacity of mechanical drive for 32 industries in 1920–39. These figures have been used to divide industries into intensive and less intensive electric motor using industries.[28]

According to *table 2*, Electric machinery and cables, Printing and publishing and Tobacco products had the highest value of electric motor capacity as a share of total mechanical drive. Grain mill products, Lumber products and Dairy had the lowest values.[29] *Table 2* shows that the difference between some of the industries classified as intensive and less intensive technology-using industries can be very small. However, the average electric motor capacity as a share of total capacity of mechanical drive is quite large between the two different industry groups. Therefore, it is of interest to investigate

[28] Electric machinery and cables is defined as the electric motor producing industry (see section 2.2.1).
[29] One reason that Grain mill products were late in adopting electric motors could be that the torque curve for steam engines were quite steep and electric motors with the same torque curves were very expensive.

whether the contribution to labor productivity growth differs between intensive and less intensive technology-using industries following electrification.

Table 2: Average electric motor capacity as a share of total capacity of mechanical drive in 1920–39 (percent)

Industry	Share
Electric motor producing industry	
Electric machinery and cables	99.9
Intensive electric motor using industries	
Printing and publishing	99.9
Tobacco products	99.9
Primary nonferrous metals	99.8
Bakery products	99.0
Machinery and equipment	97.3
Other chemical substances	96.9
Ships and boats	96.6
Fertilizers	94.5
Oil and fat	93.9
Apparel and related product	93.3
Prepared meats	92.9
Rubber products	92.9
Leather tanning and finishing	92.7
Soap and glycerin cleaning and polishing	92.5
Textile mill products	91.7
Less intensive electric motor using industries	
Confectionary and related products	91.5
Footwear except rubber	91.4
Glass products	91.4
Industrial chemicals	88.2
Fabricated metal products	87.6
Cement, lime and concrete	84.5
Brewery	82.6
Primary iron and steel	82.5
Paint and allied products	82.5
Pulp paper and paper board	79.8
Other provisions	74.9
Spirits	67.4
Sugar industries	66.2
Grain mill products	54.0
Lumber products	52.8
Dairy	46.0

Source: Kommerskollegium (1920–39) and own calculations.

Since there are no data on the ICT capital stock available for Swedish manufacturing at a disaggregated level, it has not been possible to define which industries that are intensive users of ICT in Sweden. Therefore, the classifications pioneered by Stiroh (2002) and *et al.* (2003) will be used. This implies that the classification is based on data of US capital services flow. However, according to van Ark *et al.* (2003), ICT intensive industries in the US are also ICT intensive in some EU countries.[30] Hence, it is reasonable to believe that the US ICT diffusion could also be used as a measure of ICT intensity in Swedish industries. *Table 3* presents the ICT-producing, intensive and less intensive ICT-using industries for Sweden based on van Ark *et al.* (2003).[31]

Table 3: ICT-producing, intensive ICT-using and less intensive ICT-using industries in manufacturing

Industry	ISIC
ICT-producing industries	
Office accounting and computing machinery	30
Electrical machinery and computing	31
Radio, television and communication equipment	32
Medical precision and optical instruments	33
Intensive ICT-using industries	
Wearing apparel, dressing and dying of fur	18
Printing and publishing	22
Machinery and equipment	29
Other transport equipment	35
Miscellaneous manufacturing and recycling	36–37
Less intensive ICT-using industries	
Food products	15–16
Textiles	17
Leather, leather products and footwear	19
Wood and products of wood and cork	20
Paper products	21
Coke, refined petroleum products and nuclear fuel	23
Chemicals	24
Rubber and plastic products	25
Non-metallic mineral products	26
Basic metals	27
Fabricated metal products	28
Motor vehicles, trailers and semi-trailers	34

Note: Since data for Sweden are not available at less aggregated levels than the 2-digit ISIC level, the ICT-producing industries are defined as ISIC 30–33.

Source: van Ark *et al.* (2003).

[30] van Ark *et al.* (2003) use rank correlations between the intensity of IT investments by industry to test whether ICT-intensive industries in the US are also ICT intensive in France, Germany, the Netherlands and the UK. Overall, the rankings suggest that the intensive ICT-using industries are similar across countries.
[31] The classification by van Ark *et al.* (2003) has been used since it is based on ISIC classification instead of US industry classification, which is used by Stiroh (2002).

4. Productivity growth in Sweden

Section 3 showed that electric motors diffused rapidly in Swedish manufacturing in the early twentieth century. Moreover, ICT capital as a share of the total capital stock increased from 8.6 to 11.6 percent in manufacturing in 1994–2002. This section will focus on how large the productivity effect was from technology-producing, intensive and less intensive technology-using industries during electrification and the ICT revolution.

4.1 Productivity growth in total manufacturing

Table 4 shows labor productivity growth in manufacturing for different subperiods in 1913–39 and 1970–2003. Since productivity growth is procyclical, the subperiods have been chosen so that productivity is measured at business cycle peaks in 1913–39 and at the bottom of the business cycle 1970–2003.[32]

Table 4: Annual labor productivity growth in Swedish manufacturing in 1913–39 and 1970–2003, subperiods

Period	Production value	Value added
1913–20	–2.8	–1.8†
1920–30	3.9	4.2†
1930–39	2.4	2.5†
1970–78	n.a	1.5
1978–81	n.a	2.4
1981–93	n.a	3.7
1993–2003	5.4	6.9
1990–95	n.a	7.3
1995–2000	6.3	7.4

Note: n.a = not available. †Data on value added in manufacturing in 1913–39 are based on Schön (1988) and include mining and Power, lightning and waterworks. For the productivity estimates based on production value, mining and Power, lightning and waterworks have been excluded. Labor productivity is defined as either production value or value added per person employed.

Sources: Kommerskollegium (1913–39), Schön (1988), OECD (2005) and own calculations.

[32] The business cycle estimates are based on Edvinsson (2005). Moreover, 1913, 1970 and 2003 are not years when the business cycle peaked or touched the bottom. These years have been chosen because the time series start or end in these years.

According to *table 4*, productivity growth was negative in Swedish manufacturing in 1913–20. It is likely that World War I had a negative impact on productivity during this period. It was not until the 1920s that productivity started to increase in manufacturing. Annual labor productivity growth in 1920–30 was 3.9 and 4.2 percent, depending on whether production value or value added is used to measure labor productivity. The US experienced similar increases in labor productivity growth in manufacturing during the 1920s (Kendrick (1961); David 1990; 1991). During the 1930s, productivity growth in Swedish manufacturing slowed down. Annual productivity growth in manufacturing was 2.4 and 2.5 percent in 1930–39, based on production value and value added, respectively.

Table 4 also shows that annual labor productivity in Swedish manufacturing was 1.5 percent in 1970–78. For the periods 1978–81 and 1981–93, annual labor productivity growth in manufacturing increased to 2.4 and 3.7 percent, respectively. However, the large increase in productivity growth in Swedish manufacturing occurred in 1993–2003. Annual labor productivity growth for this period was 6.9 and 5.4 percent, depending on whether value added or production value is used to measure labor productivity. For the US economy, there was an increase in productivity growth beginning in the third quarter of 1995 (see Oliner & Sichel 2000; Gordon 2000). However, labor productivity growth in Swedish manufacturing was not considerably more rapid in the period 1995–2000 as compared to the period 1990–95. Annual labor productivity growth was 7.3 and 7.4 percent in 1990–95 and 1995–2000, respectively (see *table 4*).

4.2 The contribution of different industry groups

A number of studies have shown there to be a lag in the implementation of new technologies and gains in productivity growth (see David 1991; Crafts 2004; Edquist & Henrekson 2006). *Table 4* shows that the largest productivity growth rates in Swedish manufacturing took place in the 1920s and the 1990s for the different periods investigated. This was long after the introduction of electricity and computers in manufacturing. Thus, aggregate productivity growth increased long after the introduction of new technology for both breakthroughs. But, did the contribution to labor productivity growth differ between technology-producing, intensive technology-using and less intensive technology-using industries during the two breakthroughs?

4.2.1 Electrification

Tables 5 and *6* show the impact of the electric motor producing, intensive and less intensive electric motor using industries on productivity growth in Swedish manufacturing in 1920–39. According to *table 5*, the annual contribution of the electric motor producing industry was 0.15 percentage points of the annual labor productivity growth of 3.93 percent in 1920–30. The corresponding figures for the intensive and less intensive electric motor using industries were 1.80 and 2.31 percentage points. This clearly shows that less intensive electric motor using industries contributed more to productivity growth than intensive using industries.

Productivity growth for intensive electric motor using industries was 4.4 percent, compared to 4.1 percent for less intensive electric motor using industries. Hence, productivity growth was slightly higher in industries using electric motors more intensively.[33] Moreover, productivity growth in the electric motor producing industry was 6.6 percent. Thus, the electric motor producing industry had a higher productivity growth than the intensive and less intensive electric motor using industries.

Oil and fat, Primary nonferrous metals and Soap and glycerine cleaning and polishing had the highest annual productivity growth in 1920–30. However, the industry contributing most to labor productivity growth was Pulp, paper and paper board with an annual contribution of 0.85 percentage points in 1920–30. Printing and publishing, Other provisions and Footwear except rubber had the lowest productivity growth in 1920–30. Moreover, the reallocation term was negative for all three different industry groups. Thus, on average, labor input increased in sectors with a lower level of labor productivity

[33] A simple OLS regression has been run where the dependent variable is labor productivity growth and the independent variable a dummy taking 1 for electric motor intensive industries and 0 for other industries. The results show that labor productivity growth does not differ significantly in intensive electric motor using industries compared to less intensive electric motor using industries.

growth. However, the combined effect of the reallocation term was quite small as compared to the industry-specific contribution (see *table 5*).

Table 5: Annual labor productivity growth and the contribution to labor productivity growth by industry in Swedish manufacturing, 1920–30

Industry	*Annual LP growth*	*Industry-specific contribution*	*Reallocation term*	*Contribution to LP growth*
Electric motor producing industry	**6.6**	**0.17**	**–0.03**	**0.15**
Electric machinery and cables	6.6	0.17	–0.03	0.15
Intensive electric motor using industries	**4.4**	**2.00**	**–0.20**	**1.80**
Printing and publishing	–1.6	–0.05	–0.02	–0.07
Tobacco products	7.7	0.23	–0.16	0.08
Primary nonferrous metals	9.9	0.02	0.002	0.03
Bakery products	1.0	0.02	0.02	0.04
Machinery and equipment	4.1	0.40	–0.07	0.33
Other chemical substances	6.9	0.09	0.001	0.09
Ships and boats	8.1	0.15	0.01	0.16
Fertilizers	7.6	0.05	0.003	0.05
Oil and fat	11.2	0.14	0.02	0.16
Apparel and related product	3.3	0.06	–0.08	–0.02
Prepared meats	8.6	0.19	0.05	0.24
Rubber products	2.6	0.03	–0.01	0.02
Leather tanning and finishing	2.9	0.05	–0.01	0.03
Soap and glycerin cleaning and polishing	8.7	0.16	–0.01	0.15
Textile mill products	4.7	0.45	0.05	0.49
Less intensive electric motor using industries	**4.1**	**2.32**	**–0.01**	**2.31**
Confectionary and related products	3.8	0.04	0.01	0.05
Footwear except rubber	0.7	0.02	0.006	0.02
Glass products	2.6	0.02	0.004	0.03
Industrial chemicals	8.0	0.10	0.005	0.10
Fabricated metal products	3.5	0.18	–0.03	0.15
Cement, lime and concrete	4.5	0.12	–0.10	0.03
Brewery	3.3	0.08	0.001	0.08
Primary iron and steel	4.6	0.17	0.01	0.18
Paint and allied products	8.2	0.02	0.00005	0.02
Pulp paper and paper board	7.3	0.82	0.03	0.85
Other provisions	0.2	0.004	0.03	0.03
Spirits	4.4	0.08	–0.01	0.08
Sugar industries	4.8	0.23	–0.04	0.19
Grain mill products	2.5	0.11	–0.01	0.10
Lumber products	1.2	0.10	0.02	0.12
Dairy	6.4	0.22	0.06	0.29
Residual				**–0.33**
Total	**3.93**			**3.93**

Note: Labor productivity is defined as production value per person employed.

Source: Kommerskollegium (1920–30) and own calculations.

Table 6: Annual labor productivity growth and the contribution to labor productivity growth by industry in Swedish manufacturing, 1930–39

Industry	*Annual LP growth*	*Industry-specific contribution*	*Reallocation term*	*Contribution to LP growth*
Electric motor producing industry	**3.0**	**0.11**	**–0.06**	**0.05**
Electric machinery and cables	3.0	0.11	–0.06	0.05
Intensive electric motor using industries	**2.5**	**1.24**	**–0.19**	**1.05**
Printing and publishing	–0.6	–0.02	–0.05	–0.07
Tobacco products	3.1	0.09	–0.02	0.07
Primary nonferrous metals	11.6	0.08	0.03	0.11
Bakery products	2.0	0.04	0.01	0.05
Machinery and equipment	2.6	0.35	–0.28	0.07
Other chemical substances	1.2	0.02	0.03	0.05
Ships and boats	4.3	0.09	–0.02	0.07
Fertilizers	2.4	0.01	0.0008	0.01
Oil and fat	–5.8	–0.06	0.02	–0.04
Apparel and related product	3.4	0.08	–0.15	–0.07
Prepared meats	2.3	0.07	0.19	0.26
Rubber products	10.1	0.14	–0.03	0.11
Leather tanning and finishing	–0.04	–0.0005	0.01	0.01
Soap and glycerin cleaning and polishing	6.2	0.11	0.05	0.16
Textile mill products	2.5	0.24	0.02	0.26
Less intensive electric motor using industries	**2.6**	**1.29**	**0.05**	**1.34**
Confectionary and related products	4.3	0.05	0.01	0.06
Footwear except rubber	0.5	0.01	0.003	0.01
Glass products	4.3	0.04	–0.01	0.02
Industrial chemicals	2.9	0.02	0.01	0.03
Fabricated metal products	2.8	0.18	–0.09	0.09
Cement, lime and concrete	5.4	0.14	0.02	0.17
Brewery	1.8	0.04	0.0006	0.04
Primary iron and steel	1.7	0.08	–0.02	0.05
Paint and allied products	5.2	0.02	0.01	0.03
Pulp paper and paper board	3.8	0.39	–0.0004	0.39
Other provisions	3.1	0.06	0.07	0.13
Spirits	–0.8	–0.01	0.003	–0.01
Sugar industries	5.8	0.16	–0.01	0.15
Grain mill products	0.8	0.02	–0.003	0.02
Lumber products	–0.7	–0.04	0.02	–0.01
Dairy	2.9	0.11	0.05	0.16
Residual				**–0.07**
Total	**2.37**			**2.37**

Note: Labor productivity is defined as production value per person employed.

Source: Kommerskollegium (1930–39) and own calculations.

According to *table 6*, the contribution from the electric motor producing industry was 0.05 percentage points of the annual productivity growth of 2.37 percent in 1930–39. The corresponding figures for intensive and less intensive electric motor using industries were 1.05 and 1.34 percentage points. Once again, less intensive electric motor using industries contributed more to productivity growth than intensive electric motor using industries. Moreover, annual labor productivity growth was 2.6 percent for industries using electric motors less intensively as compared to 2.5 percent for intensive users of electric motors. Productivity growth in the industry producing electric motors was 3.0 percent. Hence, labor productivity growth continued to be slightly higher in the industry producing the new technology, compared to the industry using it.

Primary nonferrous metals, Rubber products and Soap and glycerin cleaning and polishing had the highest annual labor productivity growth rates. Pulp, paper and paper board continued to contribute most to labor productivity growth in Swedish manufacturing in 1930–39. Moreover, Oil and fat, and Spirits and Lumber products had the lowest labor productivity growth in 1930–39. The reallocation term was small in relation to the industry-specific contribution. However, for some industries, such as Machinery and equipment, the reallocation term was quite large.[34]

4.2.2 The ICT revolution

Table 7 shows the contribution of ICT-producing, intensive and less intensive ICT-using industries to annual labor productivity growth in Swedish manufacturing in 1993–2003. The annual contribution of ICT-producing industries to labor productivity growth was 1.91 percentage points of the annual productivity growth of 5.40 percent in manufacturing. The corresponding figures for intensive and less intensive ICT-using industries were 0.91 and 2.73 percentage points. Labor productivity growth was 13.4 percent for ICT-producing industries as compared to 4.0 and 4.2 percent for intensive and less intensive ICT-using industries. Moreover, the reallocation term was quite small for all three different industry groups.

[34] The reason for this is that the productivity level for Machinery and equipment was lower than the average productivity level for manufacturing. Thus, when labor resources increase in Machinery and equipment, there is a negative effect on aggregate productivity growth.

Table 7: Annual labor productivity growth and the contribution to labor productivity growth by industry in Swedish manufacturing, 1993–2003

Industry	*Annual LP growth*	*Industry-specific contribution*	*Reallocation term*	*Contribution to LP growth*
ICT-producing industries	**13.4**	**1.93**	**–0.02**	**1.91**
Office accounting and computing machinery	3.8	0.02	0.01	0.03
Electrical machinery and computing	3.3	0.09	–0.01	0.08
Radio, television and communication equipment	20.8	1.70	–0.003	1.70
Medical precision and optical instruments	4.3	0.12	–0.02	0.10
Intensive ICT-using industries	**4.0**	**0.85**	**0.06**	**0.91**
Wearing apparel, dressing and dying of fur	7.3	0.02	0.002	0.02
Printing and publishing	2.7	0.14	0.05	0.19
Machinery and equipment	4.4	0.49	–0.02	0.47
Other transport equipment	2.7	0.06	0.0004	0.06
Miscellaneous manufacturing and recycling	5.3	0.14	0.02	0.17
Less intensive ICT-using industries	**4.2**	**2.73**	**0.00**	**2.73**
Food products	2.1	0.21	–0.03	0.18
Textiles	5.0	0.04	0.01	0.04
Leather, leather products and footwear	6.8	0.01	0.0008	0.01
Wood and products of wood and cork	4.2	0.20	0.0006	0.20
Paper products	3.6	0.30	–0.03	0.27
Coke, refined petroleum products and nuclear fuel	–0.4	–0.01	0.03	0.02
Chemicals	4.9	0.37	0.02	0.39
Rubber and plastic products	3.4	0.08	–0.01	0.08
Non-metallic mineral products	2.8	0.05	0.01	0.06
Basic metals	3.5	0.23	–0.004	0.22
Fabricated metal products	2.4	0.15	–0.06	0.09
Motor vehicles, trailers and semi-trailers	8.5	1.10	0.06	1.16
Residual				–0.14
Total manufacturing	**5.40**			**5.40**

Note: Labor productivity is defined as production value per person engaged.

Source: Statistics Sweden (2005) and own calculations.

The Radio, television and communication equipment (RTC) industry had a very high labor productivity growth with 20.8 percent per year in 1993–2003. Moreover, the contribution of the RTC industry to total labor productivity growth in manufacturing was 1.70 percentage points, or 31.5 percent of total labor productivity growth in 1993–2003. This implies that the RTC industry had the highest productivity growth rate and contributed most to total labor productivity growth in 1993–2003. The industry with the second highest contribution was Motor vehicles, trailers and semi-trailers, which contributed 1.16 percentage points. Thus, the RTC industry and the Motor vehicles, trailers and semi-trailers accounted for 52.6 percent of total annual productivity growth in Swedish manufacturing in 1993–2003.

4.2.3 Comparing electrification and the ICT revolution

Table 8 shows the relative contribution to labor productivity growth of technology-producing, intensive and less intensive technology-using industries for subperiods in 1920–39 and 1993–2003. According to *table 8*, the relative contribution of the electric motor producing industry was 3.4 and 2.0 percent of total labor productivity growth in manufacturing in 1920–30 and 1930–39. The corresponding figures for the ICT-producing industry were 34.4 percent in 1993–2003. Hence, the relative contribution of the technology-producing industry was considerably larger during the ICT revolution as compared to electrification.

Table 8: Relative contribution by each industry group to labor productivity growth in Swedish manufacturing, subperiods

Industry group	*1920–30*	*1930–39*	*1993–2003*
Technology-producing	3.4	2.0	34.4
Intensive technology-using	42.4	43.0	16.4
Less intensive technology-using	54.2	55.0	49.2
Total	100	100	100

Note: Labor productivity is defined as production value per person employed in 1920–39 and production value per person engaged in 1993–2003. To make comparisons possible, residuals have been excluded from the relative contribution.

Sources: Kommerskollegium (1920–39), Statistics Sweden (2005) and own calculations.

The relative contribution of intensive electric motor using industries in 1920–30 and 1930–39 was 42.4 and 43.0 percent, respectively. The corresponding figures for the ICT revolution were 16.4 percent in 1993–2001. Hence, industries that were intensive users of electric motors contributed more, in relative terms, to labor productivity growth in

Swedish manufacturing in 1920–39 than intensive ICT-using industries in 1993–2003. The relative contribution to annual labor productivity growth by less intensive electric motor using industries was 54.2 percent in 1920–30 and 55.0 percent in 1930–39. In 1993–2003, the contribution of less intensive ICT-using industries was 49.2 percent. Hence, the relative contribution of less intensive technology-using industries was slightly larger during electrification than during the ICT revolution.

According to *table 8*, one of the major differences in productivity growth following each breakthrough is the contribution by the technology-producing industries. The contribution to labor productivity growth was much larger in industries producing the new technology during the ICT revolution as compared to electrification. One reason for this is that the RTC industry had a much higher productivity growth than Electric machinery and cables. Productivity growth in the Swedish RTC industry was 20.8 percent in 1993–2003, while the corresponding figure for Electric machinery and cables was 6.6 and 3.0 percent in 1920–30 and 1930–39, respectively. Moreover, ICT-producing industries as an average share of total production value in 1993–2003 were 14.3 percent, while the corresponding figure for Electric machinery and cables was 3.1 percent in 1920–39.

According to Pilat & Devlin (2004), the share of ICT-producing industries is relatively large in Sweden compared to many other countries. This raises questions of whether the large contribution to labor productivity growth of the ICT-producing industries is an exclusively Swedish phenomenon or if ICT-producing industries have contributed substantially to labor productivity growth also in other counties?

Table 9 shows labor productivity growth, contribution and relative contribution to labor productivity growth from each industry group in France, Germany, the UK and the US.[35] According to *table 9*, the only country where the contribution of ICT-producing manufacturing to labor productivity growth was higher than in Sweden, in absolute terms, was the US. The US ICT-producing industry accounted for 4.10 percentage points of the

[35] The data presented in *table 9* are based on the 60-industry database provided by the Groningen Growth and Development Centre (2006). The results presented in *table 9* are based on national deflators for all industries, including the ICT-producing industry.

annual 5.53 percent labor productivity growth in manufacturing in 1993–2003. The corresponding figure for Sweden was 1.91 percentage points of the 5.40 percent labor productivity growth in manufacturing in 1993–2003 (see *table 7*).[36]

Table 9: Annual labor productivity growth, contribution and relative contribution to labor productivity growth in manufacturing in four countries 1993–2003

	France	*Germany†*	*UK*	*US*
Annual labor productivity growth				
ICT-producing industries	9.7	4.5	6.0	25.5
Intensive ICT-using industries	3.4	2.4	1.0	1.2
Less intensive ICT-using industries	2.1	2.3	1.2	2.6
Total manufacturing	3.12	2.69	1.96	5.53
Contribution to LP growth				
ICT-producing industries	1.16	0.66	0.74	4.10
Intensive ICT-using industries	0.84	0.64	0.28	0.34
Less intensive ICT-using industries	1.33	1.34	0.69	1.50
Residual	–0.21	0,05	0.25	–0.41
Total manufacturing	3.12	2.69	1.96	5.53
Relative contribution††				
ICT-producing industries	34.9	25.0	43.3	69.0
Intensive ICT-using industries	25.2	24.3	16.2	5.7
Less intensive ICT-using industries	39.9	50.7	40.4	25.3
Total manufacturing	100	100	100	100

Note: †German figures are for the period 1993–2002. ††Residuals have been excluded from the relative contribution. Labor productivity growth is defined as value added per person engaged. National deflators are used for all industries including the ICT-producing industries.

Source: Groningen Growth and Development Centre (2006).

Even though the contribution of the ICT-producing industry to labor productivity growth, in absolute terms, is lower in the other three European countries, the relative contribution is quite high for these countries. According to *table 9*, the relative contribution was 43.3, 34.9 and 25.0 in the UK, France and Germany, respectively. Hence, the ICT-producing

[36] US labor productivity growth is defined as value added per person engaged, while the Swedish labor productivity figures are defined as production value per person engaged in 1993–2003. This is due to the lack of value added in fixed prices for the Swedish RTC industry in 2002–2003. Estimates of productivity growth based on value added and production value should not be directly compared. However, productivity estimates based on value added show the main results to be the same if value added is used for the period 1993–2001.

industries accounted for a large part of labor productivity growth in manufacturing in these countries .

4.3 Services

So far, this paper has focused on productivity growth in manufacturing. The primary reason for this is that there are no reliable estimates of productivity growth for the service sector during electrification. Moreover, characteristics of services tend to change frequently and services are often tailored to each customer's individual needs. Thus, it is very difficult to measure the quality improvement of services and productivity measures of services are therefore often questioned. Nonetheless, in 2003, the production value of the service sector accounted for 52 percent of the production value of the total Swedish business sector. The corresponding figure for manufacturing was 38 percent. Thus, despite the difficulties in measuring productivity in services, it is important to use the available data to test whether the same conclusions about the productivity growth pattern are valid also when productivity estimates for services are included.

Table 10 shows the contribution of ICT-producing, intensive and less intensive ICT-using industries for the whole business sector in Sweden and the US in 1993–2001.[37] The figures for Sweden must be interpreted with great caution since accurate price indexes are missing for many Swedish services. For those services where price indexes are missing, Statistics Sweden uses the change of wages in each service sector to estimate production value and value added in fixed prices.

According to *table 10*, US labor productivity growth was higher in the intensive ICT-using service sector, compared to the corresponding industry in Sweden. Labor productivity growth in Swedish and US intensive ICT-using services was 1.8 and 3.8 percent, respectively. Moreover, annual US labor productivity growth was 26.1 percent in ICT-producing manufacturing compared to 20.6 percent for the corresponding industry in Sweden. However, Swedish labor productivity growth was considerably higher than that

[37] Comparable productivity estimates for the US and Sweden are only available based on value added. Hence, productivity growth could only be compared for the period 1993–2001, because data on value added for the Swedish RTC industry are only available in 1993–2001.

in the US in intensive and less intensive ICT-using manufacturing. Altogether, productivity growth in the Swedish and US business sector in 1993–2001 was 2.77 and 2.07 percent, respectively.

Table 10: Annual LP growth, contribution and relative contribution to LP growth in the Swedish and the US business sector in 1993–2001

	Sweden	*US*
Annual labor productivity growth		
ICT-producing manufacturing	20.6	26.1
ICT-producing services	1.4	2.2
Intensive ICT-using manufacturing	3.8	0.4
Intensive ICT-using services	1.8	3.8
Less intensive ICT-using manufacturing	4.7	1.4
Less intensive ICT-using services	0.3	0.2
Other less intensive ICT-using industries	0.7	0.5
Total business sector	2.77	2.07
Contribution to LP growth		
ICT-producing manufacturing	0.66	0.81
ICT-producing services	–0.01	0.10
Intensive ICT-using manufacturing	0.27	0.03
Intensive ICT-using services	0.41	1.09
Less intensive ICT-using manufacturing	0.80	0.15
Less intensive ICT-using services	0.28	0.15
Other less intensive ICT-using industries	0.08	0.09
Residual	0.28	–0.36
Total business sector	2.77	2.07
Relative contribution†		
ICT-producing manufacturing	26.4	33.4
ICT-producing services	–0.4	4.3
Intensive ICT-using manufacturing	10.8.	1.1
Intensive ICT-using services	16.5	44.9
Less intensive ICT-using manufacturing	32.2	6.3
Less intensive ICT-using services	11.1	6.3
Other less intensive ICT-using industries	3.3	3.7
Total business sector	100	100

Note: †Residuals have been excluded from the relative contribution. Labor productivity growth is defined as value added per person engaged. National deflators are used for all industries. The definitions of ICT-producing industries, intensive and less intensive ICT-using industries are based on van Ark *et al.* (2003). However, due to the lack of data for some industries, it has not been possible to use the exact definitions set up by van Ark *et al.* (2003). Therefore, ISIC 30–33 are defined as ICT-producing industries and ISIC 50–52 and 73–74 as intensive ICT-using services.

Sources: Statistics Sweden (2005) and Groningen Growth and Development Centre (2006).

In absolute terms, the contribution to labor productivity growth was 1.09 percentage points in US intensive ICT-using services, while the corresponding figure for Sweden was 0.41 percentage points. Hence, the relative contribution of intensive ICT-using services was 44.9 percent in the US compared to 16.5 percent for Sweden. Moreover, the US also had a higher relative contribution from ICT-producing manufacturing. However, the contribution from intensive ICT-using manufacturing, and less intensive ICT-using manufacturing was considerably larger in Sweden, both in absolute and relative terms. For example, the contribution from less intensive ICT-using manufacturing was 0.80 percentage points for Sweden compared to 0.15 for the US.

These results correspond well with the findings of van Ark *et al.* (2003) which investigate the differences in service sector productivity growth between the US and EU-countries. According to van Ark *et al.* (2003), the largest difference between Europe and the US can be found for ICT intensive services in 1995–2000. This can be explained by a much higher productivity growth for US Retail and wholesale trade and Financial services compared to the corresponding industries in most EU-countries. However, the contribution to labor productivity growth from intensive and less intensive manufacturing industries is considerably larger in Sweden compared to most western EU countries.

Table 10 shows that the contribution of ICT-producing manufacturing industries to labor productivity growth remains very high both in Sweden and the US when services are included. The relative contribution to labor productivity growth from Swedish ICT-producing manufacturing is 26.4 percent of the total business sector, while the corresponding figure for the US is 33.4 percent. Hence, even when services are included, the contribution to labor productivity growth of the technology-producing industry is considerably higher during the ICT revolution than during electrification in Sweden.

4.4 Measurement errors

In section 4.2, it was shown that productivity growth was higher in ICT-producing industries in the 1990s compared to productivity in the industry producing electric motors in 1920–39. One of the reasons for this is the tremendous improvement in the technology of ICT products since the introduction of the microprocessor in the 1970s. According to many empirical observations, the number of transistors per square inch of an integrated circuit has doubled every 18 months since the 1970s.[38] To capture the fast quality improvements of ICT products, many statistical agencies started to use hedonic price indexes for ICT products in the 1990s.[39] The hedonic methodology is extensively used for ICT products in the US, while European countries have been slower in adopting hedonic methods (van Mulligen 2003). In Sweden, hedonic price indexes are used for imported PCs, but not for telecommunication equipment products.

When hedonic price indexes are not used, statistical agencies use matched model price indexes. The matched model is constructed comparing exactly the same model of specific products in two time periods. The price index is computed by matching the price for the second period with that in the initial period. Models that cannot be matched are excluded. When statistical agencies match models based on different assessments, they also introduce a quality bias. This quality bias comes in two forms: inside and outside the sample bias. The inside type of bias occurs when prices of non-identical products are matched. The outside kind of bias occurs when price changes of matched models are not representative of price changes of unmatched models. This bias is often strong, if the share of matched models is low (van Mulligen 2003).

The largest productivity growth in Swedish ICT-producing industries took place in the RTC industry. Hedonic price indexes are not used for this industry, but it is likely that the use of the matched model methodology to measure price changes for telecommunication equipment products give rises to large inside and outside the sample bias. Many telecommunication products are sold as large complex systems and are often tailor made for customers. Moreover, Edquist (2005a) shows that the methods used to deflate

[38] This empirical observation is often refereed to as Moore's law after the co-founder of Intel Gordon E. Moore.

[39] A hedonic price index is a price index making use of a hedonic function. A hedonic function is a relation between the prices of different product models, such as the various models of personal computers, and the quantities of characteristics in them (Triplett 2004).

intermediate inputs such as semiconductors can have a large effect on the measured productivity growth in the RTC industry.[40]

The price indexes used for Electric machinery and cables are matched model price indexes based on Ljungberg (1990). At a more disaggregated level, Electric machinery and cables (1) consists of Electric machinery (1a) and Electric cables and electronic apparatus (1b). Edquist (2005b) has constructed hedonic price indexes for Electric machinery (1a). He finds that during the 1920s, PPI-deflated hedonic price indexes decreased by 4.8 percent per year. This is a clear indication of rapid productivity growth in the electric motor producing industry in Sweden during the 1920s. If the hedonic price indexes provided by Edquist are used to calculate labor productivity growth for Electric machinery (1a) in 1920–30, annual labor productivity growth becomes 14.8 percent. What would the effect on labor productivity be if these price indexes were used to calculate labor productivity growth for Electric machinery and cables (1)?

Table 11 shows annual labor productivity growth, contribution and relative contribution for Electric machinery and cables (1) when the hedonic price indexes for electric motors based on Edquist (2005b) are used. The calculations use a price index for Electric cables and electronic apparatus (1b) based on Ljungberg.[41] According to *table 11*, annual labor productivity growth of Electric machinery and cables (1) increases from 6.6 percent to 9.0 percent, when hedonic price indexes are used.

Nonetheless, the increase in contribution and relative contribution to labor productivity growth is moderate. The relative contribution increases from 3.4 percent of annual total labor productivity growth to 4.8 percent when hedonic price indexes are used for Electric machinery. The corresponding figure for the ICT-producing industries was 34.4 percent in 1993–2003. Hence, the relative impact of the technology-producing industry on labor

[40] The findings of Edquist (2005a) are only valid as long as value added is used to estimate productivity growth for the RTC industry. When production value is used instead of value added, there are no separate price indexes for intermediate inputs.
[41] The price index of cables and electronic apparatus is based on the price development of two different cables, named OVI and HVG (see Ljungberg 1990). The two price indexes have been equally weighted.

productivity growth was considerably higher during the ICT revolution than during electrification, even when hedonic price indexes are used.

Table 11: Annual labor productivity growth, contribution and relative contribution to labor productivity growth for Swedish Electric machinery and cables based on different price indexes in 1920–30

	1920–30
Electric machinery and cables (matched model price indexes based on Ljungberg 1990)	
LP growth	6.6
Contribution to LP growth	0.15
Relative contribution to LP growth	3.4
Electric machinery and cables (hedonic price indexes for electric motors based on Edquist 2005b) †	
LP growth	9.0
Contribution to LP growth	0.21
Relative contribution to LP growth	4.8

Note: Electric machinery and cables (1) consists of Electric machinery (1a) and Cables and electronic apparatus (1b). †The productivity growth estimates for Electric Machinery (1a) are based on hedonic price indexes provided by Edquist (2005b), while the estimates for Cables and electronic apparatus (1b) are based on matched model price indexes provided by Ljungberg (1990). The price index for Cables and electronic apparatus (1b) is an equally weighted price index of two different electric cables, named OVI and HVG (see Ljungberg 1990 p. 319).

Sources: Ljungberg (1990), Edquist (2005b) and own calculations.

The primary reason for the larger impact of the technology-producing industry during the ICT revolution is that the production value and labor compensation shares were considerably larger for the ICT-producing industry. The average production value and labor compensation share for the ICT-producing industry were both 14.3 percent in 1993–2003. The corresponding figures for Electric machinery and cables were 3.1 and 5.6 percent in 1920–39, respectively. Thereby, the technology-producing industry contributed considerably more to labor productivity growth, even when hedonic price indexes are used for electric motors.

5. Conclusions

Swedish manufacturing was rapidly electrified in the early twentieth century. In 1906, electric motors accounted for 18.6 percent of the mechanical drive capacity in Swedish manufacturing, while the corresponding figure in 1939 was 88.9 percent. Hence, the share of thermal and hydroelectric power used for mechanical drive decreased as steam engines and water wheels were transformed into driving generators. These findings support earlier investigations of the diffusion of electricity in Swedish manufacturing (see Hjulström 1940; Schön 1990). However, horsepower capacity does not always reflect the work output and therefore, it is likely that the electrification of manufacturing was not as rapid as suggested by Swedish capacity data. According to Du Boff (1979), the capacity utilization of electric motors was lower compared to steam engines. Hence, there is reason to believe that the electrification of the direct mechanical drive in Swedish manufacturing was somewhat slower in terms of capacity utilization.

For the period 1980–1999, there is a lack of data on the diffusion of ICT products in Swedish manufacturing. Still, it was possible to show that ICT as a share of the capital stock in Swedish manufacturing increased from 8.6 percent in 1994 to 11.6 percent in 2002. In 2000, the share of firms using computers was 96–99 percent and by 2003, more than 60 percent of all employees in Swedish manufacturing firms were working with computers. Moreover, the share of manufacturing firms with access to the Internet increased from 89 percent in 2000 to 96 percent in 2005. Hence, by 2000, computers were well integrated in the production process of Swedish manufacturing firms.

Stiroh (2002) defines the ICT intensive industries in the US as those industries with an above median value of the 1995 ICT share of capital services. The industries with below median value are defined as less intensive ICT-using industries. The classification of Swedish ICT-producing, intensive and less intensive using industries is based on Stiroh (2002) and the ICT-producing industries are defined according to OECD (2002).[42]

[42] Since there were no data of the ICT capital stock available for Swedish manufacturing, it has not been possible to identify which industries are intensive users of ICT in Sweden. Hence, the classification must be

During electrification, industries with an above median value of the average electric motor capacity as a share of total mechanical drive capacity in 1920–39 was defined as intensive users of electric motors. This definition is a good indication of how far the process of replacing old production equipment had proceeded in each industry. According to Devine (1983) and David (1991), the replacement of old production by installing electric motors resulted in a number of productivity enhancing opportunities.

To measure the contribution of each industry to labor productivity growth, the decomposition method recommended by OECD (2001) was used (see section 2.2.3). Annual labor productivity growth in the electric motor producing industry was 6.6 and 3.0 in 1920–30 and 1930–39, respectively. The corresponding figures for the intensive and less intensive electric motor using industries were 4.4 and 4.1 percent in 1920–30 and 2.5 and 2.6 percent in 1930–39. Thus, labor productivity growth was slightly higher for the electric motor producing industry, compared to the intensive and less intensive electric motor using industries.

The relative contribution to labor productivity growth in manufacturing from the electric motor producing industry was only 3.4 percent compared to 42.4 and 54.2 percent for the intensive and less intensive electric motor using industries in 1920–29. In 1930–39, annual labor productivity growth decreased to 3.0 percent and relative contribution to 2.0 percent for the electric motor producing industry. The relative contribution to labor productivity in manufacturing for intensive and less intensive using industries was 43.0 and 55.0 percent in 1930–39.

For the ICT revolution, annual labor productivity growth was 13.4 percent for the ICT-producing industry, compared to 4.0 and 4.2 percent for the intensive and less intensive ICT-using industries in 1993–2003. The relative contribution to labor productivity growth in manufacturing was 34.4 percent for the ICT-producing industry. The corresponding figures for the intensive and less intensive ICT-using industries were 16.4 and 49.2 percent.

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based on US data provided by Stiroh (2002). However, van Ark *et al.* (2003) suggest that the intensive ICT-using industries are similar in the US and a number of European countries.

The results of the contribution to labor productivity growth following electrification and the ICT revolution show that the impact of the technology-producing industry in manufacturing was considerably larger following the ICT revolution compared to electrification. The ICT-producing industry was considerably larger both in terms of labor productivity growth and production value, compared to the electric motor producing industry. The average share of total production value for the ICT-producing industries was 14.3 percent in 1993–2003, while the corresponding figure for Electric machinery and cables was 3.1 percent in 1920–39.[43] Moreover, the relative contribution to labor productivity growth of ICT-producing industries in manufacturing was also very high in other countries such as France, Germany, the UK and the US. Thus, it was not only in Sweden that ICT-producing industries accounted for a large share of the contribution to labor productivity growth in the 1990s.

During the ICT revolution, many statistical agencies started to use hedonic price indexes to capture the fast quality improvement of ICT products. The effect of hedonic price indexes raises questions of whether productivity would be higher if hedonic price indexes were used for the electric motor producing industry. Estimates show that the annual labor productivity growth of Electric machinery and cables increases from 6.6 percent to 9.0 percent if hedonic price indexes based on Edquist (2005b) are used instead of matched model price indexes based on Ljungberg (1990). Nonetheless, the impact on productivity growth from the electric motor producing industry remains small, even when hedonic price indexes are used. The main reason for this is that production and labor compensation shares were considerably smaller for the electric motor producing industry as compared to the ICT-producing industry.

One of the major differences between electrification and the ICT revolution is that the service sector was considerably larger during the latter. Therefore, it is possible that the

[43] One possible reason for this could be that it has been easier for Swedish ICT firms to expand internationally during the 1990s compared to firms producing electrical equipment in the 1920s. According to Glete (1983), it was difficult for the largest Swedish electric equipment manufacturer ASEA to export some of its products due to protectionism and cartelization in other countries.

impact of the ICT-producing industries decreases if the service sector is included in the analysis. However, calculations on the relative contribution to labor productivity growth show that ICT-producing manufacturing still accounts for as much as 26.4 percent of total labor productivity growth in Sweden when services are included. The corresponding figure for the US was 33.4 percent.

This paper has shown that the contribution to labor productivity growth in the technology-producing industry was considerably higher in Swedish manufacturing during the ICT revolution as compared to electrification. However, the relative contribution of the intensive technology-using industry was considerably higher during electrification, while the relative contribution of the less intensive technology-using industry remained approximately the same. These findings have an important policy implication, namely that it is much more important how productivity is measured for ICT products than for electric motors in the 1920s. The measurement methods of prices for ICT products differ considerably between countries, which must be taken into consideration when productivity is compared across countries.

9. Appendix

Appendix A: The revision of Swedish industry classification in 1913

The revision of the Swedish industry classification in 1913 implied a number of major changes. These are listed below.

1. Mining is included in the official statistics.
2. The following new groups of industrial facilities are included: Dairy, Waterworks and Repair shops for the Swedish state owned railway company.
3. Only industrial facilities with a) more than 10 persons employed and b) with a production value of more than 10 000 SEK or a value added of 3000 SEK are included in the official statistics.
4. Different products produced within the same facility are reported separately.

5. A new classification system is used, where production value is reported at a more aggregated level than before.
6. Production value is reported either as sales value of final products in each industry or the sum of the value of the final products and the intermediary products produced.[44]

Appendix B: Estimation of labor compensation

Labor compensation has been estimated for the years 1920, 1930 and 1939. The estimates are based on data of wages and the number of individuals employed provided by the Swedish Statistical Yearbook (SSY) (1922–42) and Kommerskollegium (1920–39). According to Kommerskollegium (1920–39), individuals employed can be divided into workers and administrative staff.

The SSY presents wages for workers in each industry. According to the SSY, wages differed widely depending on whether the workers were male, female or individuals aged below 18.[45] The share of each worker category in total employment is used to weight the wages in each industry. The weighted wages are added to arrive at an average annual wage for each industry. Finally, the average annual wage in each industry is multiplied by the total number of workers employed in that industry. Thus, total labor compensation for workers is estimated for each industry.

For administrative staff, there are no wages available for different industries and gender. Instead, SYY presents estimates of different wages for three different categories of administrative staff, namely engineers, clerks and sales clerks. According to Kommerskollegium (1920), there is also another group of administrative staff namely

[44] In this paper, the production value based on the sales values of the final products has been used to avoid double counting to the largest possible extent.
[45] The wage of female workers was only approximately 60 percent of that of male workers throughout the period 1920–39. Moreover, for many industries, wages are only available for male workers. For these industries, it is assumed that the proportional wage difference between male, female and individuals aged below 18 is the same as for total manufacturing.

management. Unfortunately, there are no wages available for managers and they are therefore excluded.[46]

Data on the number of engineers, clerks and sales clerks for each industry group are only available for the year 1920. Therefore, the share of engineers, clerks and sales clerks is calculated for each industry in 1920. These shares are then used to weight each of the different wages for engineers, clerks and sales clerks. The shares are then added for each industry and multiplied by the total number of administrative staff in each industry. Since data of engineers, clerks and sales clerks are not available for the years 1930 and 1939, the shares of different administrative staff for these years are based on the shares in 1920. Finally, total labor compensation for workers and administrative staff is added for each industry.

[46] By excluding management, it is assumed that managers were paid approximately the same wages in all industries and that the number of managers in each industry is proportional to the number of other employees in that industry.

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PAPER 4

The Swedish ICT Miracle – Myth or Reality*

Harald Edquist

Abstract

This article investigates the productivity development in Sweden in the 1990s. The results show that much of the recorded Swedish surge in labor productivity was due to the spectacular growth of the Radio, television and communication equipment (RTC) industry. However, this article shows that the productivity growth of the RTC industry is very sensitive to value added price deflators. Unlike Sweden, the US uses hedonic price indexes for semiconductors and microprocessors which are important intermediate inputs in the RTC industry. Estimates based on the US intermediate input price deflators for semiconductors and microprocessors suggest that the productivity growth of the Swedish RTC industry during the 1990s is an artefact. This implies that the productivity growth of total manufacturing has also been overestimated. The results for Sweden are also interesting for other countries such as Finland, Ireland and South Korea where ICT-producing industries have contributed substantially to labor productivity growth.

JEL Classification : O10, O30, O47, O57

Keywords: Information and communication technology (ICT), Productivity, Technological change, Value added deflators

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1. Introduction

During the 1990s productivity research increasingly came into focus. Comparisons of productivity across countries and industries are important for evaluating economic performance. Moreover, particular attention has been paid to productivity comparisons in industries with rapid technological change and falling prices such as the information and communication technology (ICT) producing industries.[1]

Comparing productivity in industries producing homogenous products is an easy task. For example, in the crude oil industry, output is arrived at by a mere counting of barrels of oil produced. Measuring productivity in industries where technology changes rapidly is a totally different matter. According to "Moore's law" microprocessors are halved in price and doubled in capacity every 18 months. A computer based on the latest technology may become obsolete within a year or two. Is it then reasonable to compare productivity in industries with rapidly changing technology and prices across countries? Nordhaus (1997) argues that capturing the impact of new technologies on living standards is beyond the practical ability of official Statistical Agencies. The essential difficulty is that high-tech products consumed today may not even have existed a decade ago. Moreover, if they did, the quality of the goods that we consume today is much higher compared to the quality of "the same" goods a decade ago.

The increase in productivity growth in the US economy since 1995 (see Council of Economic Advisers 2003) has resulted in an intense debate on the impact of ICT technology on productivity in different countries. In Sweden, ICT technology created an economic boom in the late 1990s. In 2000 Stockholm was named the Internet capital of Europe by Newsweek Magazine. According to Newsweek (2000) the Stockholm

[1] OECD (2002) defines the following industries as ICT-producing: Office accounting and computing machinery (ISIC 30), Insulated wire and cable (ISIC 313), Radio, television and communication equipment (ISIC 32), Instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment (ISIC 3312) Industrial process control equipment (ISIC 3313), Wholesale of machinery, equipment and supplies (ISIC 5150), Renting of office machinery and equipment (ISIC 7123), Telecommunications (ISIC 642) and Computer and related services (ISIC 72). In this article, ISIC 30–33, 64 and 72 are defined as ICT-producing industries. This is due to the lack of reliable data at less aggregated industry levels than the 2-digit ISIC level.

phenomenon could be explained by "the looming marriage of the Internet and the third-generation mobile telephony in Europe".

Four years later, it was evident that much of the Swedish Internet era of the late 1990s was a transient hype, partly created by media. However, it has been very difficult to explain the fundamental fact that productivity growth in Swedish manufacturing and particularly in the Radio, television and communication equipment (RTC) (ISIC 32) industry increased rapidly during the 1990s. Did the increased productivity growth in manufacturing and RTC reflect some fundamental changes in the economy or was it largely a statistical illusion?

Much of the recent international debate about the ICT revolution has focused on whether ICT investments have had a substantial impact on productivity across a wide range of different industries or whether only a few industries have been affected. For the US there appears to have been an early link between the ICT investments and productivity effects in industries that are using ICT intensively (Stiroh 2002). However, there are still some skeptics such as Robert Gordon (2000), who argue that the productivity revival in the US occurred primarily within durable goods production and particularly in the ICT-producing industries.

Unlike the experience of the US in the late 1990s, there was little evidence of a widespread productivity increase in Swedish manufacturing (Edquist & Henrekson 2002). Instead, the Swedish ICT miracle was confined to the ICT-producing industries and particularly in the RTC industry. Figures from Statistics Sweden show that for the period 1993–2001 the annual labor productivity growth in RTC was approximately 40 percent. Without the spectacular growth of the Swedish RTC industry the productivity growth in total manufacturing during the second half of the 1990s would have been much lower. The increasing importance of the RTC industry for the Swedish economy during the 1990s raises important questions about the problems associated with correctly measuring productivity in ICT-producing industries. These problems are not only important for Sweden. Pilat & Wölfl (2004) show that Finland, Ireland and South Korea had a higher contribution of ICT-producing manufacturing to aggregate productivity growth than Sweden during 1996–2002.

The problems with measuring productivity in ICT-producing industries will be investigated in this article by analyzing the productivity performance in the Swedish economy during the 1990s. The results show that the Swedish RTC industry was the industry that contributed most to the aggregate Swedish productivity performance in the 1990s. Since the RTC industry is characterized by rapidly changing technologies it is complicated to measure and compare productivity for this industry. Therefore, I also provide a detailed investigation of the RTC industry. An important question that will be addressed is to what extent the productivity growth in the Swedish RTC industry was affected by country specific value added price deflators?

In section 2, I present evidence of the productivity performance in the Swedish economy during the 1990s. The productivity development is investigated both from a growth and level perspective. Section 3 investigates the impact of using value added price deflators on productivity measures in the ICT-producing industries. Section 3 also compares the intermediate input and gross output price deflators for RTC in Sweden and the US. Section 4 concludes.

2. Labor productivity comparisons

2.1 Growth comparisons

Table 1 presents the labor productivity growth rates in manufacturing and the economy as a whole in Sweden and 18 other OECD countries during the 1990s.[2] According to *table 1* the annual labor productivity growth rate in Swedish manufacturing was 6.3 percent in 1990–2001. The only country that had a higher productivity growth rate in manufacturing during the same period was South Korea at 9.2 percent. All other countries, except Finland, experienced a labor productivity growth rate below 4 percent in manufacturing

[2] Labor productivity is defined as value added per person engaged. The reason to use value added instead of production value as a measure of labor productivity is due to better data availability for value added.

during the 1990s. *Table 1* also shows that the labor productivity growth for the total Swedish economy was 2.5 percent for the same period. The annual productivity growth rate for the total Swedish economy was considerably lower than the annual productivity growth rate in Swedish manufacturing. Moreover, even though the annual productivity growth rate for the Swedish economy was one of the highest compared to other OECD countries, the difference in growth rate relative to other OECD countries was much smaller for the total economy compared to manufacturing.

Table 1: Annual labor productivity growth in manufacturing and the total economy for 19 OECD countries 1990–2001

Country	*Manufacturing*	*Total economy*
Australia	2.4	2.0
Austria	3.9	2.0
Belgium	2.7	1.3
Canada	3.1	1.6
Denmark	2.6	1.7
Finland	5.1	2.5
France	3.5	1.0
Germany†	2.4	1.7
Italy	2.0	1.3
Japan	2.6	1.2
Luxemburg	3.5	1.6
Netherlands	2.6	0.7
New Zealand	2.3	1.1
Norway	0.9	2.4
Spain	1.6	0.9
South Korea	9.2	4.4
Sweden	6.3	2.5
United Kingdom	2.6	2.2
United States	3.6	1.5

Notes: †Growth rates for Germany are for the period 1991–2001. The countries have been included after data availability.

Source: OECD (2001b).

Recent studies of productivity performance and ICT has focused on whether ICT has had any substantial impact on productivity in a wide range of different industries and not only in the ICT-producing industries. Stiroh (2002) and van Ark *et al.* (2003) distinguish between ICT-producing industries, intensive ICT-using industries and less intensive ICT-using industries.[3] Stiroh (2002) finds that in the US, the ICT-producing and the intensive ICT-using industries accounted for all of the productivity revival (after 1995) that can be attributable to the direct contributions from specific industries. Moreover, Oliner and Sichel (2000) estimate that the growing use of ICT equipment and the efficiency improvement in computer production accounted for about two-thirds of the one percentage point increase in labor productivity growth between the first and the second half of the 1990s. Even though ICT has had an important effect on the productivity performance in the US, the evidence for other OECD countries are much weaker (Jalava & Pohjola 2002). van Ark *et al.* (2003) have shown that ICT diffusion in Europe is following a similar industry pattern as in the US, but at a slower pace. Moreover, the key difference between Europe and the US are in intensive ICT-using services, where US productivity growth rates increased substantially more than in Europe in the second half of the 1990s.

With regard to the international debate about ICT, an interesting question is which Swedish industries that have contributed most to the productivity growth during the 1990s? To answer this question, I use industry data of value added, employment and labor compensation from the Swedish national accounts (Statistics Sweden 2003). Due to changes in industrial classification and the introduction of the new 1993 system of national accounts (SNA), the Swedish industry data only cover the period 1993–2001 at the 2-digit ISIC level. Moreover, it has not been possible to estimate total factor productivity (TFP) growth, since there are no official data on the capital stock in Sweden during the 1990s. It is also important to point out that the measurement of quality and prices in the Swedish service sector are highly uncertain. Statistics Sweden does not use any consistent method to measure prices in the service sector. Instead of prices, Statistics Sweden uses the change of wages in each service sector to calculate value added in fixed prices. Therefore, productivity results for the Swedish service sectors must be interpreted with caution.

[3] Stiroh (2002) defines an intensive ICT-using industry as an industry with above median ICT share of capital services in 1995. van Ark *et al.* (2003) largely base their distinction of ICT intensive and less ICT intensive industries on the definition provided by Stiroh (2002).

Despite these caveats, *table 2* presents labor productivity growth in 1993–2001 for industries at the 2-digit ISIC level for ICT-producing industries, intensive ICT-using industries and less intensive ICT-using industries.[4]

According to *table 2* the highest labor productivity growth in the Swedish economy was found for the ICT-producing industries with an annual labor productivity growth of 8.4 percent per year in 1993–2001. The intensive ICT-using industries had an annual productivity growth rate of 2.3 percent, while the annual growth rate in the less intensive ICT-using industries was 1.9 percent. Moreover, the productivity growth rate in manufacturing was considerable higher than in services in all three industry categories. The highest productivity growth for an industry at the 2-digit ISIC level was found for the RTC industry with an average annual growth rate of 41.2 percent. The second highest productivity growth rate was found for Motor vehicles, trailers and semi-trailers at 10.0 percent.

Table 2 also shows calculations of the contribution of each industry to labor productivity growth in all industries in 1993–2001.[5] The calculations are based on the method used by Pilat & Wölfl (2004). In short, the average industry specific value added growth is weighted with the current-price share of each industry in value added, while the industry level labor input is obtained by weighting the growth rate of number of persons engaged by industry with each industry's share in total labor compensation.

[4] Industries have been divided into ICT-producing, intensive ICT-using and less intensive ICT-using industries according to van Ark *et al.* (2003). However, due to the lack of data for some industries, it has not been possible to use the definitions of van Ark *et al.* for all industries. Therefore, ISIC 30–33 are defined as ICT-producing industries, ISIC 50–52 and ISIC 73–74 are defined as intensive ICT-using industries and ISIC 17–19 are defined as less intensive ICT-using industries.

[5] All industries include market producers and producers of final use which means that most of the Swedish public sector is excluded.

Table 2: Labor productivity growth and the contribution to labor productivity growth by industry in Sweden 1993–2001

Industry	*ISIC*	*Growth rate*	*Contribution to LP growth*		
		1993–2001	1993–1996	1996–2001	1993–2001
ICT-producing industries		**8.4**	**1.20**	**0.29**	**0.61**
Manufacturing		***19.3***	***0.96***	***0.45***	***0.61***
Office, accounting and computing machinery	30	5.7	0.01	0.01	0.01
Electrical machinery and computing	31	3.3	–0.01	0.04	0.02
Radio, television and communication equip.	32	41.2	0.96	0.35	0.55
Medical precision and optical instruments	33	4.1	0.01	0.05	0.04
Services		***1.5***	***0.23***	***–0.16***	***0.003***
Communications	64	7.2	0.33	0.18	0.23
Computer and related services	72	–2.7	–0.09	–0.34	–0.23
Intensive ICT-using Industries		**2.3**	**1.05**	**0.39**	**0.62**
Manufacturing		***3.8***	***0.39***	***0.18***	***0.26***
Printing and publishing	22	2.7	0.12	0.03	0.06
Machinery and equipment	29	4.6	0.25	0.09	0.15
Other transport equipment	35	–0.8	–0.04	0.02	–0.01
Manufacturing, recycling n.e.c	36–37	7.3	0.06	0.05	0.05
Services		***1.8***	***0.66***	***0.21***	***0.36***
Wholesale and retail trade	50–52	3.4	0.78	0.25	0.45
Financial institutions and insurance	65–67	2.0	0.18	0.07	0.11
Renting of machinery and equipment	71	5.1	0.01	0.05	0.03
Research and development	73–74	–1.2	–0.32	–0.16	-0.23
Less-intensive ICT-using industries		***1.9***	***1.59***	***0.95***	***1.19***
Manufacturing		***4.6***	***0.85***	***0.73***	***0.78***
Food products	15–16	3.2	0.20	0.01	0.08
Textile, clothing, leather and footwear	17–19	2.8	0.02	0.01	0.01
Wood and products of wood and cork	20	6.2	0.10	0.05	0.07
Paper products	21	1.4	–0.08	0.09	0.03
Coke, refined petroleum and nuclear fuel	23	8.2	0.05	0.004	0.02
Chemicals	24	5.1	0.07	0.20	0.15
Rubber and plastic products	25	4.4	0.02	0.03	0.03
Non-metallic mineral products	26	2.9	0.001	0.03	0.02
Basic metals	27	4.0	0.10	0.04	0.06
Fabricated metal products	28	2.4	0.05	0.01	0.03
Motor vehicles, trailers and semi-trailers	34	10.0	0.32	0.25	0.28
Other services		***0.3***	***0.46***	***0.24***	***0.32***
Hotels and Restaurants	55	2.3	0.03	0.04	0.03
Inland transport	60	3.6	0.23	0.07	0.13
Water transport	61	1.9	0.04	–0.01	0.01
Air transport	62	–5.2	–0.01	–0.04	–0.03
Supporting and auxiliary transportation	63	1.5	0.01	0.02	0.02
Real estate activities	70	2.2	0.19	0.19	0.19
Educational, health and social work	80–85	–1.3	–0.10	–0.08	–0.09
Other community and personal service	90–95	2.4	0.06	0.05	0.05
Other industries		***0.8***	***0.28***	***–0.02***	***0.09***
Agriculture, forestry, fishing	01–05	3.3	0.01	0.07	0.05
Mining and quarrying	10–14	2.0	0.02	0.001	0.01
Electricity, gas and waterworks	40–41	2.2	0.004	0.07	0.05
Construction industry	45	0.1	0.25	–0.16	–0.02
Residual			**0.14**	**0.48**	**0.39**
Total		**2.81**	**3.98**	**2.10**	**2.81**

Sources: Statistics Sweden (2003) and own calculations.

According to *table 2*, the ICT-producing industries contributed 0.61 percentage points to the annual labor productivity growth in all industries of 2.81 percent in 1993–2001. The contribution from the intensive ICT-using industries and the less intensive ICT-using industries was 0.62 and 1.19 percentage points, while there was a residual of 0.39 percentage points. Interestingly the contribution of the RTC industry was 0.55 percentage points in 1993–2001 which is approximately 20 percent of the total contribution to labor productivity growth in all industries.

Table 2 also shows the contribution from industries for the periods 1993–1996 and 1996–2001. The reason for choosing 1996 as a breakpoint is because productivity growth increased substantially in the US after 1995. However, for Sweden productivity growth was higher in 1993–96 than during 1996–2001. In fact, the growth rate decreased by 1.9 percentage points in the latter period. In contrast to the US, the relative importance of the ICT-producing industries, and the intensive ICT-using industries decreased in 1996–2001 compared to 1993–95.

It is important to point out that other factors than ICT can have a large impact on productivity growth. For example industrial policy, economic policy in general and business cycles also affects productivity growth. Gordon (2000) attributes a sizeable part of the US labor productivity in the late 1990s to cyclical factors. The results presented here do not control for business cycle effects. However, even though other factors can have large effects on productivity growth there is much evidence suggesting that ICT have been very important for productivity growth in the US during the 1990s. For example, Stiroh (2002) and van Ark *et al.* (2003) find a robust correlation between the ICT intensity and the acceleration in US productivity growth during the second half of the 1990s. Inklaar and McGuckin (2003) use filtering techniques and find that the cyclical effects in the US were generally small, except for the year 2000–2001. From the discussion above it is clear that ICT alone can not explain all of the productivity growth in the Swedish economy during the 1990s. Nevertheless, it is evident that the important story of the Swedish productivity performance in the 1990s was the spectacular productivity growth in the Swedish RTC industry.

There are several other studies of the Swedish productivity growth in the 1990s. Pilat & Wölfl (2004) use data from the OECD STAN database for the period 1990–1999. They find that annual labor productivity growth for the total economy decreased from 2.95 percent in 1990–95 to 2.67 percent in 1996–1999. The contribution from the RTC industry to total labor productivity increased from 0.19 to 0.43 percentage points during the two periods. Even though, Pilat and Wölfl do not use the data from the Swedish national accounts of 2003, their results support the findings in *table 2*. van Ark *et al.* (2003) also estimate labor productivity growth in Sweden 1990–2000. However, they use data based on an old version of the STAN database. Unlike the results in *table 2*, van Ark *et al.* do not find the same increase in the contribution of the RTC industry as suggested by *table 2*. One reason is that they use US value added deflators for the Swedish ICT-producing industries. By applying the US ICT-deflators on Sweden one implicitly assumes that the industry structure and price changes for the ICT-producing industries would be identical in the two countries. The empirical validity of these assumptions is questionable. In section 3, I therefore analyze the effects on the productivity growth in ICT-producing industries when these assumptions are relaxed.

2.2 Productivity level comparisons

Section 2.1 described the Swedish productivity performance from a growth perspective. However, it is also important to investigate the productivity performance of a country from a level perspective.

2.2.1 Unit value ratios

To compare labor productivity levels between countries with different currencies, it is necessary to convert the value added of different countries into a common currency. Since price levels in different industries can vary substantially across countries, it is also necessary to find a conversion method that is industry specific (Scarpetta *et al.* 2000). According to van Ark & Timmer (2002) there are two alternative ways to construct reliable industry level Purchasing Power Parities (PPPs). The first approach is to transform expenditure PPPs to industry groups by "peeling off" indirect taxes and transport and distribution margins and thereby create producer price level PPPs.[6] The second approach is the industry-of-origin methodology that will be used in this article.[7] The industry-of-origin approach converts the currency by using output data instead of expenditure data. The conversion is made by calculating unit value ratios (UVRs).

The industry-of-origin approach is here used to compare productivity levels between Germany, Sweden and the US. The unit value ratios are based on two bilateral investigations for the year 1997. The first investigation compares the unit value ratios between Germany and Sweden and the second compares the unit value ratios between Germany and the US. This allows for comparisons of Sweden and the US by using Germany as a link. The unit value ratios between Sweden and Germany are based on data from the Eurostat Prodcom-database (Europroms 2001). The unit value ratios between Germany and the US have been calculated by Inklaar *et al.* (2003b) and are based on the Eurostat Prodcom-database and the US manufacturing census for 1997. Due to the lack of data it has not been possible to calculate UVRs for the service sector and the comparison of productivity levels therefore covers manufacturing only.

The results of the relative productivity level for the benchmark year (1997) have been extended to other years by using labor productivity growth rates. Labor productivity growth rates are calculated by using time series for value added, value added deflators and employment. The labor productivity growth rates are then used to calculate the change in relative productivity performance based on the benchmark year. The Swedish time series data were taken from the Swedish national accounts.[8] The time series of value added, value added deflators and employment for total manufacturing was extended using data from the STAN database for 1980–1992 (OECD 2001b). This makes it possible to present estimates of the productivity levels in Swedish manufacturing for the period 1980–2001. The data for Germany and the US are based on the 60-industry database

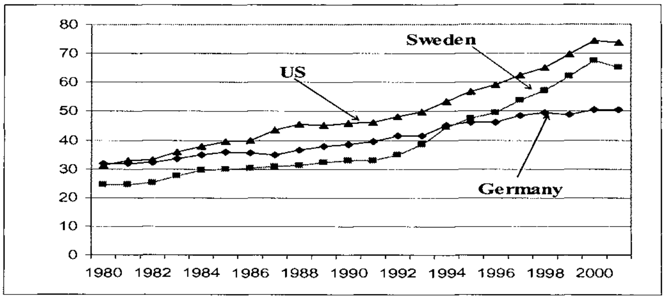
[6] This method was pioneered by Jorgenson and associates. For a more detailed description of the method see van Ark & Timmer (2002).
[7] The industry-of-origin methodology has been developed by the ICOP (International Comparisons of Output and Productivity) group at the University of Groningen since 1983 (see van Ark & Pilat 1993). For a detailed description of the industry-of-origin methodology see appendix A.
[8] As pointed out in section 2.1 the Swedish national accounts only covers the period 1993–2001.

(GGDC 2003). Furthermore, all aggregation for the US and Germany have been based on Törnqvist weights.[9]

2.2.2 Productivity level results[10]

The labor productivity level estimates for total manufacturing for Germany, Sweden and the US are presented in *figure 1*.[11] The results in *figure 1* indicate that the productivity level in Swedish manufacturing was well below that of Germany and the US at the beginning of the 1980s.

Figure 1: Labor productivity levels in manufacturing, value added in fixed prices per person engaged in Germany, Sweden and the US 1980–2001



Notes: Calculations are based on official value added deflators. The currency used is thousands of Euros. The calculations for Germany before 1991 are based on figures for West Germany.

Sources: GGDC (2003), Europroms (2001), OECD (2001b), Statistics Sweden (2003) and own calculations.

During the 1980s Sweden caught up slightly with Germany, while the productivity gap between Sweden and the US increased. During the late 1980s and the beginning of the 1990s relative productivity levels remained unchanged. However, from 1993 to 2001 Sweden was catching up with Germany and the US. In 1995 Sweden overtook Germany in terms of labor productivity and the productivity gap between the two countries

[9] See appendix B.

[10] The productivity level results are based on calculations of UVRs presented in Edquist (2004). In short, for Sweden and Germany 802 different product groups were matched and the coverage ratio was 25 percent of the German production value and 37 percent of the Swedish. The corresponding figures for Germany and the US were 516 matches and 28 percent coverage ratios for both countries (see Edquist 2004).

[11] The labor productivity level results for total manufacturing are based on domestic deflators.

increased during the period 1995–2000. Moreover, the labor productivity gap between Sweden and the US was only 5 percent in 2001 compared to 33 percent in 1993.

The results for total manufacturing seem to correspond well with the growth patterns of total manufacturing presented in *table 1*. However, Inklaar *et al.* (2003a) present estimates of labor productivity levels in manufacturing for EU countries and the US. According to the results in Inklaar *et al.* (2003a) labor productivity in Swedish manufacturing increased from 93.5 to 99.3 percent of the US level between 1979–81 and 1994–1996. However, relative labor productivity fell to 86.6 percent in 1999–01. The fall in Swedish labor productivity for manufacturing in the late 1990s is not supported by the results presented in *figure 1*. One possible explanation is that Inklaar *et al.* (2003a) use harmonized US deflators for ICT-producing industries, while the results in *figure 1* are based on national deflators.[12] Another possible reason for the difference is that the data used by Inklaar *et al.* (2003a) are primarily based on an old version of the STAN database instead of the most recent figures from the Swedish national accounts.[13]

3. ICT-deflators and labor productivity

3.1 ICT-deflators

In section 2 it was shown that the use of different value added price deflators for the ICT-producing industries have a large impact also on measured productivity in manufacturing. Applying the US deflators for all three countries automatically assumes that the industry structure of the Swedish and German ICT-producing industries is identical to the US and that the price development for all ICT products would be the same in all three countries. These assumptions are not empirically valid. An interesting question then is what effect the use of different value added deflators has on measured productivity?

[12] The use of different value added deflators will be discussed in detail in section 3.
[13] See Statistics Sweden (2003)

Table 3: Value added deflators for the ICT-producing industries (ISIC 30–33) in 1994–2001

	1994	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*
Germany								
Office, accounting and computing machinery	–0.17	-0.05	–0.01	–0.06	–0.06	–0.09	–0.13	n.a.
Electric machinery and computing	–0.002	–0.001	0.02	–0.01	0.004	0.01	–0.02	n.a.
Radio, television and communication equip.	–0.02	–0.01	–0.004	–0.003	–0.04	–0.04	–0.07	n.a.
Medical, precision and optical instruments	0.01	0.02	0.03	0.03	0.01	0.03	–0.008	n.a.
Sweden								
Office, accounting and computing machinery	0.04	0.02	0.06	–0.01	0.02	0.01	–0.004	0.21
Electric machinery and computing	0.05	0.07	0.12	0.008	–0.03	–0.07	–0.05	0.021
Radio, television and communication equp.	–0.41	–0.51	–0.40	–0.30	–0.39	–0.39	–0.51	n.a.
Medical, precision and optical instruments	0.06	0.02	0.05	0.007	–0.03	–0.03	–0.09	0.06
US								
Office, accounting and computing machinery	–0.23	–0.29	–0.50	–0.56	–0.56	–0.51	–0.23	–0.31
Electric machinery and computing	0.006	0.01	0.03	0.02	0.03	0.01	–0.01	0.02
Radio, television and communication equip.	–0.14	–0.41	–0.35	–0.26	–0.41	–0.35	–0.41	–0.35
Medical, precision and optical instruments	0.04	0.07	0.14	0.08	0.13	0.07	0.06	0.11

Note: n.a. = not available.

Sources: GGDC (2003), Statistics Sweden (2003) and own calculations.

Table 3 shows the deflators based on the calculations from each country's statistical office.[14] The approximation of the Swedish deflators to the German and US deflators are described in Appendix B. The US deflators for Office, accounting and computing machinery (OAC) (ISIC 30) are much more negative than those for Sweden and Germany. Interestingly, the German deflators are more negative than the Swedish ones for OAC. One reason for this finding could be that the structure of the industry is very different in the two countries. For example, the German OAC industry could be

[14] An exact description of how value added price deflators are calculated is presented in section 3.2.

producing more semiconductors and microprocessors, while the corresponding industry in Sweden produces other types of computer equipment. For RTC the Swedish deflators are more negative than both the US and German deflators for all years except 1998 when the US deflator is slightly more negative than the Swedish one. The deflators for Electric machinery and computing (ISIC 31) and for Medical, precision and optical instruments (ISIC 33) do not differ as much as the other two ICT-producing industries in the three countries.

Table 4 presents the result for relative labor productivity levels for Sweden and Germany when different ICT-deflators are used.[15] The results indicate that the use of different deflators have very large impacts on labor productivity levels for OAC and for RTC. If the US deflators are used for the German OAC industry, while the Swedish deflators are applied to the same industry in Sweden, this results in a substantial decline in the relative labor productivity level for the Swedish OAC industry. According to *table 4* the labor productivity level for OAC went from being 18 times higher than the German level in 1993 to becoming only one half of the German labor productivity level in 2000. This appears nonsensical and there is no empirical evidence that can justify these results. Nevertheless, the results clearly show how sensitive productivity calculations are to large differences in value added deflators over a longer time period. In the other two cases (see *table 4*), the productivity level in the Swedish OAC industry remains higher relative to the same industry in Germany for the period 1993–2000.

For RTC the Swedish labor productivity level increases relative to that of Germany when country specific deflators are used. When the US deflators are applied for Germany and the country-specific ones for Sweden, the result shows that Swedish relative labor productivity increased for the period 1993–1997. After 1998 there is a decline in the Swedish relative labor productivity level and in 2000 the higher productivity level in Sweden has almost disappeared. When the US deflators are applied on both countries, there is a similar decline in the Swedish relative labor productivity level after 1998. For the year 2000 the relative labor productivity level is only 93 percent of the German labor

[15] The relative labor productivity levels are based on UVR estimates for Sweden and Germany in 1997. The estimates are presented in Edquist (2004).

productivity level. On the other hand, if country specific deflators are used for both countries the productivity level is increasing throughout the period 1993–2000.[16] In conclusion, the results presented in *table 4* show that the use of different deflators for the ICT-producing industries has a large influence on relative labor productivity between Sweden and Germany.

Table 4: Relative productivity level in Sweden and Germany with different ICT-deflators (Germany=100) 1993–2000

Sweden = Swedish deflators Germany = German deflators	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
Office, accounting and computing machinery	207	166	160	173	144	149	130	110
Electric machinery and computing	83	84	88	82	75	87	86	91
Radio, television and communication equipment	7	14	35	78	136	182	219	228
Medical, precision and optical instruments	86	84	85	79	89	100	99	84
Sweden = Swedish deflators Germany = US deflators								
Office, accounting and computing machinery	1842	1370	954	533	144	106	67	52
Electric machinery and computing	78	80	84	80	75	89	88	94
Radio, television and communication equipment	29	49	79	113	136	136	129	104
Medical, precision and optical instruments	67	68	72	74	89	112	115	110
Sweden = US deflators Germany = US deflators								
Office, accounting and computing machinery	136	137	144	200	144	155	151	146
Electric machinery and computing	65	69	78	81	75	84	77	80
Radio, television and communication equipment	70	73	95	121	136	137	126	93
Medical, precision and optical instruments	81	84	85	81	89	97	90	74

Note: Calculations of productivity levels in the ICT-producing industries are based on UVR estimates for 1997 at the 2-digit ISIC level presented in Edquist (2004).

Sources: GGDC (2003), Europroms (2001), Statistics Sweden (2003) and own calculations.

[16] To compare labor productivity growth rates for Germany and Sweden with country specific value added deflators is very problematic, since Sweden uses other types of quality adjustments than Germany.

3.2 A detailed investigation of the RTC industry

During the period 1993–2000 measured labor productivity growth in the Swedish RTC industry was 41 percent p.a. Calculations presented in *table 2* showed that the RTC industry contributed approximately 20 percent to the total labor productivity growth in Swedish industries in 1993–2001.[17] During the same period the gross output in the Swedish RTC industry as a share of gross output in manufacturing, increased from 4 percent in 1993 to 12 percent in 2000. The corresponding figures for Germany and the US were approximately 2 and 6 percent in 1993–2001. The number of persons engaged in the Swedish RTC industry as a share of total manufacturing increased from around 4 percent in 1993 to 6 percent in 2000.[18]

It is evident that the Swedish RTC industry became increasingly important for the Swedish economy during the 1990s.[19] It is therefore crucial that the productivity development in the Swedish RTC industry is correctly measured. *Table 4* showed that the use of different deflators for the RTC industry has enormous effects on measured productivity growth. By using US deflators also for the German and Swedish ICT-producing industries one implicitly assumes that the structure of the ICT-producing industries is the same in all three countries and that the price fluctuations of output and intermediate input prices are identical. In this section, I investigate what happens with the deflators for the Swedish and the US RTC industry when these assumptions are relaxed.

When comparing ICT-deflators across countries it is crucial to understand how value added in different countries is deflated. Both the Swedish and the US national accounts are based on double deflation to arrive at value added in fixed prices. Double deflation implies that the value of gross output and intermediate inputs are deflated separately with an output price index and an intermediate input price index, respectively. These two

[17] Swedish industries include market producers and producers of final use which means that most of the Swedish public sector is excluded.
[18] The number of persons engaged in computer and related services also increased considerably during the 1990s (Johansson 2004).
[19] Much of the growth of the RTC industry in the 1990s was due to the success of the Swedish telecommunications equipment manufacturing company Ericsson.

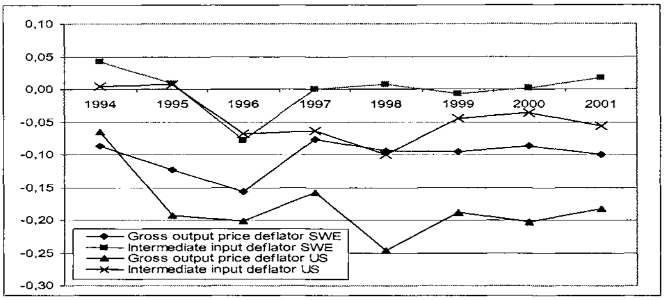
series are then used to arrive at value added in fixed prices. More specifically, value added in fixed prices can be defined as an average of the price change in gross output $(\frac{\partial \ln P_{Output}}{\partial t})$ and the price change of intermediate inputs $(\frac{\partial \ln P_{Input}}{\partial t})$. The price change of intermediate inputs is weighted by the share of intermediate inputs in gross output $(\frac{P_{Input}M}{P_{Output}Q})$ and the entire expression is multiplied by the inverted share of value-added in gross output $(\frac{P_{Output}Q}{P_{VA}VA})$ (OECD 2001a). The exact relation for the value added price deflator and intermediate input and output prices is shown in the following expression:

$$\frac{d\ln P_{VA}}{dt} = \frac{P_{Output}Q}{P_{VA}VA}\left[\frac{d\ln P_{Output}}{dt} - \frac{P_{Input}M}{P_{Output}Q}\frac{d\ln P_{Input}}{dt}\right]. \tag{1}$$

Equation (1) shows that the price change in intermediate inputs has a large influence on the value added price deflator if the proportion of intermediate input as a share of total output is high.

Figure 2 shows the gross output and intermediate input price deflators for RTC in Sweden and the US. The US gross output and the intermediate input prices decreased more rapidly than the corresponding gross output and input prices for Sweden. The average price deflator for the Swedish intermediate inputs was zero, while the average price deflator for US intermediate inputs was –0.05 for the period 1994–2001. For output prices the average deflator was –0.10 for Sweden and –0.18 for the US. For which products did the price deflator for the intermediate input prices and for the output prices decrease more in the US compared to Sweden?

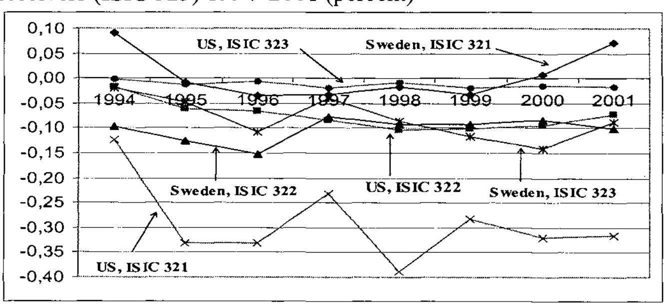
Figure 2: Gross output and input price deflators for the Radio, television and communication equipment industry (ISIC 32) 1994–2001 (percent)



Sources: GGDC unpublished data and Statistics Sweden (2003).

To answer this question I investigate the price deflators for RTC at a more disaggregated industry level. At the 3-digit ISIC industry level, RTC consists of the following three industries: Electronic valves and tubes (ISIC 321), Telecommunication equipment (ISIC 322) and Radio and television receivers (ISIC 323).[20] *Figure 3* compares the gross output price deflator for these three industries in Sweden and the US for the period 1994–2001.

Figure 3: Gross output price deflators for Electronic valves and tubes (ISIC 321), Telecommunication equipment (ISIC 322) and Radio and television receivers (ISIC 323) 1994–2001 (percent)



Sources: GGDC unpublished data and Statistics Sweden (2003).

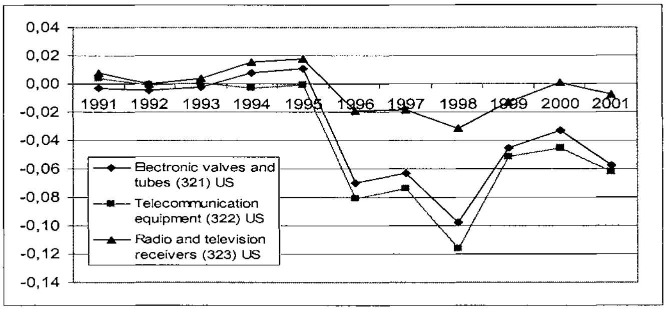
According to *figure 3* the US gross output price deflator for Electronic valves and tubes (ISIC 321) was much more negative than the corresponding Swedish deflator throughout the period 1994–2001. Moreover, the Swedish gross output price deflator for

[20] By and large, Electronic valves and tubes (ISIC 321) consists of the production of semiconductors and microprocessors.

Telecommunication equipment (ISIC 322) was approximately the same as the US deflator in 1997–2001. *Figure 3* also indicates that for the period 1994–2001 the Swedish gross output price deflator for Radio and television receivers (ISIC 323) was more negative than the corresponding US deflator.

Intermediate input price deflators for Sweden are not available at the 3-digit ISIC industry level.[21] *Figure 4* shows the US intermediate input price deflators for Electronic valves and tubes (ISIC 321), Telecommunication equipment (ISIC 322) and Radio and television receivers (ISIC 323) in 1991–2001.

Figure 4: Input price deflators for Electronic valves and tubes, Telecommunication equipment and Radio and television receivers in the US 1991–2001



Source: GGDC unpublished data.

For the period 1991–1995 the intermediate input price deflators for all three industries were close to zero. However, for the period 1996–2001 the price deflators became more negative in all three industries. The decrease was larger for Electronic valves and tubes (ISIC 321) and Telecommunication equipment (ISIC 322) compared to Radio and television receivers (ISIC 323).

One possible explanation to the larger decrease in the intermediate input and output price deflators in the US (see *figure 2*) is that the US systematically uses hedonic adjustments for semiconductors and microprocessors. This implies that the improved quality in semiconductors and microprocessors is considered when the price changes are estimated. Since the invention of the transistor in 1948 there has been an extraordinary increase in

[21] Statistics Sweden does not publish input price deflators for the 3-digit ISIC level.

the capacity of semiconductors and microprocessors. For a long time microprocessors were halved in price and doubled in capacity every 18 months.[22] In Sweden hedonic price adjustments are not used to take the quality improvements of semiconductors and microprocessors into account. This could be the reason why the gross output Swedish price deflators for Electronic valves and tubes have not decreased as much as in the US (see *figure 3*).

Since semiconductors are important intermediate inputs in Telecommunication equipment (ISIC 322) and Radio and television receivers (ISIC 323), it is likely that the use of hedonic price adjustments for semiconductors also influences the input deflators for these industries. Triplett (1996) has shown that if the output price decline in the semiconductor producing industry is underestimated this implies that the intermediate input price decline in computers is also underestimated. This means that if all intermediate inputs where produced domestically, the measured productivity for the computer industry would be correct despite the incorrect measurement of prices in the semiconductor producing industry. However, Triplett's results do not hold for the Swedish RTC industry since approximately 75 percent of the Electronic components that were used in Swedish RTC industry were imported in 1995–2001.

How would the Swedish value added price deflators change if hedonic price adjustments were made also for semiconductors in Sweden? To give an accurate answer to this question it would be necessary to have price data at a very detailed product level for Sweden and the US. This data is not available for Sweden due to secrecy. Nevertheless, *table 5* provides estimates of how value added deflators would change if hedonic price indexes were also used for semiconductors in Sweden.

The Swedish value added deflators are recalculated under the assumption that the Swedish intermediate input prices for Electronic valves and tubes (ISIC 321), Telecommunication equipment (ISIC 322) and Radio and television receivers (ISIC 323) are identical to the corresponding industries in the US. The intuition behind this

[22] This empirical regularity was named "Moore's law" after the cofounder of Intel, Gordon Moore who first made this observation in 1965.

assumption is that price changes of all intermediate inputs except semiconductors would be the same in the US and Sweden. Although it is true that prices vary between different markets, a large part of the intermediate inputs in the RTC industry is purchased globally at world market prices. Moreover, it is also assumed that the Swedish gross output price deflators for Electronic valves and tubes (ISIC 321) are equal to the corresponding industry in the US. This implies that if hedonic prices were implemented in Sweden for semiconductors and microprocessors the price decline in the semiconductor producing industry would equal that in the US. This is a plausible assumption since semiconductors are often priced and purchased at world market prices (Triplett 1996).

Neither Sweden nor the US use hedonic price indexes for estimating gross output price deflators for Telecommunication equipment (ISIC 322) and Radio and television receivers (ISIC 323). Therefore, the calculations in *table 5* for these industries are based on domestic price indexes for Sweden provided by the national accounts.[23] Finally, the prices are weighted by the specific industry structure of the Swedish RTC industry (measured as shares of production in gross output and intermediate inputs at factor costs).

Not surprisingly, the results of the recalculated deflators presented in *table 5* differ widely from the results of the official value added deflators presented in *table 3*. The largest difference can be noticed for the period 1997–2000. The recalculated value added deflators in *table 5* are all negative, but less negative than the value added deflators in *table 3*. The reason for the large difference between the deflators in *tables 3* and *5* is that the method to calculate the value added price deflator is very sensitive to the development of the intermediate input price deflators.[24] The reason why Sweden is much more sensitive to price changes in intermediate inputs than the US is that the intermediate input/gross output ratio for the Swedish RTC industry is much larger compared to the US.

[23] Both the Swedish and the US price indexes in *table 5* are expressed in domestic currencies. If PPPs are used to convert the Swedish price indexes of ISIC 322 and 323 into US dollars, the value added deflators in *table 5* will increase for some years and decrease for some other years. However, the total effect on productivity for the period 1997–2000 will remain the same.
[24] Semiconductors and microprocessors are important intermediate inputs in RTC.

Table 5: Recalculation of the Swedish value added price deflators for the Radio, television and communication industry (ISIC 32)

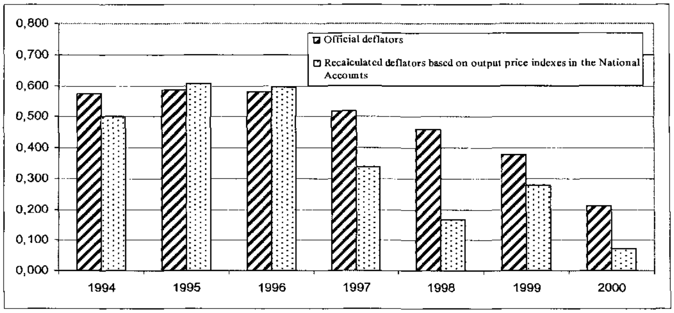
	1994	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
Gross output price deflator (1)							
Electronic valves and tubes (US)	–0.12	–0.33	–0.33	–0.23	–0.39	–0.28	–0.32
Telecommunication equipment (SWE)‡	–0.10	–0.13	–0.15	–0.08	–0.09	–0.09	–0.08
Radio and television receivers (SWE)‡	–0.02	–0.05	–0.11	–0.04	–0.09	–0.12	–0.14
Shares of gross output, measured as production at factor costs (2)							
Electronic valves and tubes	0.07	0.05	0.04	0.04	0.07	0.05	0.05†
Telecommunication equipment	0.89	0.91	0.90	0.92	0.89	0.90	0.90†
Radio and television receivers	0.04	0.04	0.06	0.05	0.04	0.05	0.05†
Gross output price deflator (3) = (1)*(2)							
Radio, television and communication equipment industry (ISIC 32)	–0.10	–0.14	–0.16	–0.08	–0.11	–0.11	–0.10
Intermediate input price deflator (4)							
Electronic valves and tubes (US)	0.01	0.01	–0.07	–0.06	–0.10	–0.05	–0.03
Telecommunication equipment (US)	0.00	0.00	–0.08	–0.07	–0.12	–0.05	–0.05
Radio and television receivers (US)	0.02	0.02	–0.02	–0.02	–0.03	–0.01	–0.00
Shares of intermediate input, measured as production at factor costs (5)							
Electronic valves and tubes	0.05	0.03	0.02	0.04	0.05	0.05	0.05†
Telecommunication equipment	0.90	0.93	0.92	0.90	0.91	0.91	0.91†
Radio and television receivers	0.04	0.04	0.06	0.06	0.04	0.04	0.04†
Intermediate input price deflator (6) = (4)*(5)							
Radio, television and communication equipment industry (ISIC 32)	–0.002	0.001	–0.08	–0.07	–0.11	–0.05	–0.04
Gross output/value added (7)‡‡	3.51	3.90	4.04	3.93	3.92	4.38	5.98
Intermediate input/gross output (8)‡‡	0.71	0.74	0.75	0.75	0.74	0.77	0.83
New value added deflators†† (9) = (7)*[(3)–(8)*(6)]	–0.34	–0.53	–0.41	–0.12	–0.10	–0.29	–0.38

Sources: GGDC unpublished data, Statistics Sweden (2003) and OECD (2003).

Notes: ‡Gross output deflators for Telecommunication equipment and Radio and television receivers are based on producer price indexes in the national accounts. ‡‡Results for gross output/value added and intermediate input/gross output are average for period t and t–1. †Shares of gross outputs and intermediate inputs for the year 2000 are assumed to be the same as for 1999. This is due to the lack of data for the year 2000. ††The new value added deflators is derived from the formula in equation 1.

Edquist (2004) shows that for the period 1993–2001, the Swedish intermediate input/gross output ratio was constantly higher than the US one. For the period 1993–1999 the Swedish intermediate input/gross output ratio was 0.7–0.8, while the corresponding figure for the US was 0.5–0.6. In 2000, the Swedish ratio increased dramatically and in 2001 intermediate inputs exceeded total gross outputs, while the US ratio remained below 0.6. Hence, value added in current prices for the Swedish RTC industry was negative. This development was largely due to the increased outsourcing by Ericsson. In Sweden a very large part of total RTC output is produced by Ericsson. This implies that the bulk of intermediate input prices reported to Statistics Sweden are determined by the pricing of one single firm, which is a source of large uncertainty in price measurement for the Swedish RTC industry.

Figure 5: Labor productivity growth rates in the RTC industry with official and recalculated deflators

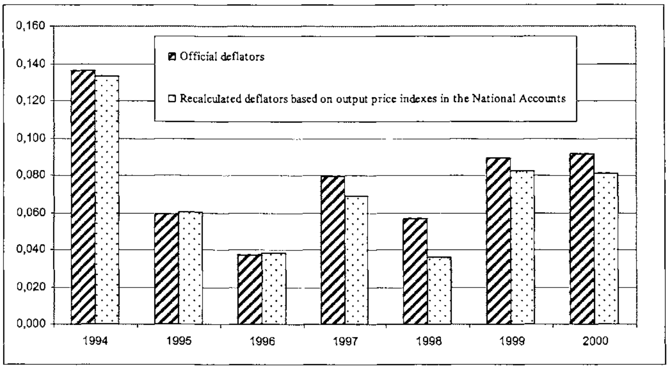


Sources: GGDC unpublished data and OECD (2003) and Statistics Sweden (2003).

The value added deflators presented in *table 5* have a great impact on how the productivity growth in the Swedish RTC industry is measured. *Figure 5* shows the labor productivity growth in the RTC industry 1994–2000 using the official value added price deflators and the recalculated deflators. Productivity growth differs widely depending on which deflators that are used. The price deflators based on the recalculated deflators lower the annual productivity growth rate by 15 percentage points from 35 to 20 percent in 1997–2000.

The use of different deflators also has implications for the productivity growth in total manufacturing. *Figure 6* shows the growth rate of total manufacturing with official and recalculated deflators. For the period 1997–2000 the growth rates of total manufacturing would be considerably smaller if the recalculated deflators are used. In 1998 the productivity growth in manufacturing would be about one third lower with the recalculated value added deflators. The conclusion is that Swedish productivity in manufacturing has been growing 1–2 percent slower compared to the official statistics.

Figure 6: Labor productivity growth rates in the total manufacturing industry with official and recalculated deflators



Sources: GGDC unpublished data and OECD (2003) and Statistics Sweden (2003).

4. Conclusions

Sweden had one of the highest labor productivity growth rates in manufacturing and in the total economy in the OECD during the 1990s. Calculations of the productivity level in Swedish manufacturing show that Sweden caught up with levels in manufacturing for Germany and the US during the 1990s. In 1995 Sweden overtook Germany in terms of labor productivity level and continued to catch up with the US throughout the period 1995–2000. However, unlike the US, there is no evidence that the Swedish productivity growth has increased considerably in a large number of industries. Instead, a large part of the labor productivity growth during the 1990s took place in the Swedish RTC industry. During the period 1993–2001 the RTC industry accounted for nearly 20 percent of the labor productivity growth in all Swedish industries. Moreover, the relative importance of the intensive ICT-using industries on labor productivity growth decreased during the second half of the 1990s (see *table 2*). The main conclusion is that the Swedish ICT miracle took place in the ICT-producing manufacturing industries and not in the ICT-using industries.

The productivity development in Sweden during the 1990s raises an important question about the different methods used by countries in order to accurately measure productivity in the ICT-producing industries. The results show that labor productivity growth rates in the ICT-producing industries are very sensitive to value added price deflators. Moreover, value added price deflators differ widely among industries and countries. The Swedish value added price deflators for RTC was considerably more negative compared to the German and US deflators throughout the period 1993–2000.[25]

One explanation to why value added price deflators are more negative for the Swedish RTC industry compared to the US is that the US Statistical Agencies systematically use hedonic adjustments for semiconductors and microprocessors, while Statistics Sweden does not.[26] Moreover, semiconductors and microprocessors are important inputs in the Swedish RTC industry. Calculations of the Swedish value added deflators based on the US price development for semiconductors and microprocessors, show that the productivity growth in the RTC industry becomes considerably lower. This suggests that the spectacular labor productivity growth exceeding 40 percent per year in 1993–2001 for the Swedish RTC industry is an illusion to a considerable extent. Moreover, the results show that it is dangerous to draw conclusions from international productivity comparisons in industries characterized by rapidly changing technology.

The overestimation of labor productivity growth for Swedish RTC also has important effects for productivity growth in total manufacturing. If the recalculated value added deflators for RTC are used to calculate labor productivity growth rates for total manufacturing, the productivity performance is 1–2 percent slower in 1997–2000 than what is suggested by official data. From a policy perspective this is an important result, because it shows that the productivity growth miracle in Swedish manufacturing during

[25] Except for the year 1998.
[26] According to Eliasson (2004) the difficulties associated with measuring quality are well known and they might result in an information paradox, namely that we are becoming less and less informed about what is becoming more and more important.

the late 1990s is partly an artefact. Moreover, Sweden is not the only country where the contribution of ICT-producing manufacturing to aggregate productivity growth has been high. Pilat & Wölfl (2004) show that Finland, Ireland and South Korea had a higher contribution of ICT-producing manufacturing to aggregate productivity growth than Sweden during 1996–2002. Further research of the implication of measuring productivity in ICT-producing industries in these countries is called for.

5. Appendix

5.1 Appendix A: Unit value ratios

The UVR-based method was first introduced in the late 1950s, but has been further refined by the ICOP (International Comparisons of Output and Productivity) group at the University of Groningen under the direction of Angus Maddison and Bart van Ark (van Ark & Timmer 2002).

Industry UVRs are based on two alternative indexes: the Laspeyres index that is using the quantity weights of the base country and the Paasche index that uses the quantity weight of the other country. As a first step, unit values (uv) are derived by dividing ex-factory output values (o) by produced quantities (q) for each product i in each economy:

$$uv_i = \frac{o_i}{q_i}. \qquad (2)$$

The unit value can be thought of as an average price, averaged throughout the year for all producers and across a group of nearly similar products. In a bilateral comparison broadly defined products with similar characteristics are matched. For each matched product, the ratio of the unit values in both countries is taken. This unit value ratio (UVR) is given by:

$$UVR_i^{xu} = \frac{uv_i^A}{uv_i^B}, \tag{3}$$

where, A and B are the countries being compared, B being the base country. The product UVR indicates the relative producer price of the matched product in the two countries.

The product UVRs are used to derive an aggregate UVR for manufacturing branches and total manufacturing. The most simple aggregation method is to weight each product UVR by its share in total manufacturing gross output.

$$UVR_j^{BA} = \sum_{i=1}^{I_j} w_{ij} UVR_{ij}^{BA}, \tag{4}$$

with i= 1,..., I_j the matched products in industry j; $w_{ij} = o_{ij} / o_j$ the output share of the i[th] commodity in industry j; and $o_j = \sum_{i=1}^{I_j} o_{ij}$ the total matched value of output in industry j. In bilateral comparisons the weights of the base country (B) or the other country (A) can be used, which provide a Laspeyres and a Paasche type UVR respectively.[27] As the quantity weights are consistent with those that are used to derive the unit values, the weights and units are consistent. The same procedure is repeated for the final aggregation step from industry level to the level of total manufacturing.

Even though, the industry-of-origin methodology is a widely used method to estimate labor productivity levels, it also has some drawbacks. van Ark (1996) point out that in many sectors and industries UVRs are based on a limited sample of items. Moreover, comparisons of unit values are affected by differences in product mix. Often output values are only calculated for product groups instead of specific products. This leads to problems on a disaggregated level because of the lack of harmonized product coding systems between different countries. Moreover, the unit value ratios also have to be adjusted to differences in product quality across countries. Another problem discussed by

[27] In this article, calculations are based on the average of the Laspeyres and Paasche indexes, i.e. the Fisher index.

van Ark (1996) is that UVRs are often used in a single deflation procedure, which means that intermediate products are not included in the estimation of UVRs.[28] Despite these caveats the industry-of-origin methodology appears to be the preferred method for comparing productivity levels across countries. Nonetheless, it is important to keep in mind that the industry-of-origin methodology has limitations and that results for industries with low coverage ratios must be interpreted with caution.

5.2 Appendix B: ICT-deflators

Even though the Swedish and the US national accounts are based on double deflation there are still differences in the way value added is measured. One important difference is that the US uses a Törnqvist price index to derive a Törnqvist value added volume index while Sweden uses a chained Paasche price index to derive a chained Laspeyres volume index, where the year t–1 is used as the base year.

A Törnqvist volume index is a weighted geometric average of the quantity relatives using arithmetic averages of the value shares in the two periods as weights.

$$Q_T = \prod_{i=1}^{n} (q_i^t / q_i^0)^{\frac{(s_i^t + s_i^0)}{2}}, \tag{5}$$

where s_i^0 denotes the share of the value of product i in the total output of goods and services in period 0: that is, $p_i^0 q_i^0 / \sum p_i^0 q_i^0$.

A Laspeyres volume index is a weighted arithmetic average of quantity relatives using the values of the earlier period as weights.

$$Q_L = \frac{\sum_{i=1}^{n} p_i^0 q_i^t}{\sum_{i=1}^{n} p_i^0 q_i^0} \equiv \sum_{i=1}^{n} (q_i^t / q_i^o) s_i^0, \tag{6}$$

[28] This article uses UVRs in a single deflation procedure since the single deflation method in practice provides more robust results for international comparisons than the double deflation method (van Ark 1996).

where s_i^0 denotes the share of the value of product i in the total output of goods and services in period 0: that is, $p_i^0 q_i^0 / \sum p_i^0 q_i^0$.

The rational for using a certain index formula is based on theoretical arguments that will not be discussed in this article.[29] However, from the definitions above there appear to be two major differences between the chained Laspeyres index and the Törnqvist index. One difference is that the Laspeyres index is based on the arithmetic average, while the Törnqvist index is based on the geometric average. Moreover, the Törnqvist price index uses the average of the two periods t and t–1 as weights while the Laspeyres index only uses the period t–1 as weights.

The logarithm of the Törnqvist index can be expressed in the following way:

$$\ln Q_T = \sum_{i=1}^{n} \frac{1}{2}(s_i^t + s_i^0) \ln\left[\frac{q_i^t}{q_i^0}\right]. \tag{7}$$

To approximate the Swedish data based on the Laspeyres index to the Törnqvist index, I use the logarithmic change of the values derived by the Laspeyres volume index. This gives the log change between two years instead of the arithmetic change. Moreover, I also use the average of the Swedish value added and intermediate input weights for the period t–1 and t. Since I do not have access to the weights of every product for the intermediate input and output it is not possible to change the weights for each product. Nonetheless, for the total gross output/value added ratio as well as for the intermediate input/gross output ratio it is possible to use the average weights of the two years t-1 and t.

[29] For a thorough discussion of the theoretical reasons to use certain index formula, see IMF (2003).

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