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Technology Regimes and Productivity Growth in Europe and the United States: A Comparative and Historical Perspective

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Abstract

Over the past decade much has been published on the contribution of information and communication technology (ICT) to economic growth. In an attempt to find parallel historical evidence, several scholars have attempted to review the contribution of other general purpose technologies (notably steam and electricity) to output and productivity growth. Most of these contributions have had a national focus on the United States and for a limited number of European countries (for example, Finland, Sweden, The Netherlands and the United Kingdom).

In this paper we review the evidence from these individual studies from an international comparative perspective. This should help us to better understand how general purpose technologies (steam, electricity and ICT) have contributed to differentials in productivity growth between European countries and the United States. In addition to the evidence from the macroeconomic perspective we also focus on the diffusion of technologies by industry, for which we exploit information on technology adoption and productivity growth by industry and their contributions to the aggregate.

We conclude that in terms of the speed of diffusion, the ICT era is comparable to the electricity age, i.e., a relatively rapid diffusion across the economy. But the impact of ICT on productivity growth is, at least for the time being, less pervasive than for electricity. The diffusion is strongest in market services, but European countries generally seem to have fallen behind the U.S.. The paper speculates that non-technological factors may have interacted more intensively with technology use during the ICT era than during the electricity and steam ages.

1. Introduction

Explosive growth of investment in information and communication technology (ICT) was at the centre of the unrealistic expectations that surrounded the ‘new economy’ hype during the late 1990s. The slowdown in investment in ICT since 2000 has somewhat tempered the enthusiasm, but the question remains how much ICT contributes to productivity growth in the longer run. As ICT can typically be characterized as a General Purpose Technology (GPT) technology, one would expect longlasting effects beyond the investment cycle.

Strikingly with the boom in ICT investment during the 1990s, labour productivity growth in the U.S. accelerated from 1.1 percent in 1987-1995 to 2.5 percent in 1995–2004. In contrast average annual growth rate of labour productivity, measured as value added per hour worked, in the European Union fell from 2.3 percent to 1.4 percent over the same period.[2]

The acceleration in productivity growth in the U.S. has spurred a burst of academic research on both sides of the Atlantic. Most of the macroeconomic research concluded that ICT accounted for much of the acceleration in productivity growth in the U.S..[3] In Europe, attention focused on how much of the slower productivity growth could be tied to differences in ICT diffusion relative to the U.S.. Various studies at the economy-wide level suggested that slower growth rates of ICT investment were an important factor in explaining the poorer European productivity performance.[4]

The macroeconomic studies only provided indirect evidence on the differential productivity effects of the *production* versus the *use* of ICT. The production effects of ICT mainly relate to the comparative advantage of the U.S. in ICT producing industries, in particular the production of semi-conductors and computer hardware. Only a limited number of small European countries, notably Finland and Ireland, have similar comparative advantages in the production of telecommunication equipment and computer hardware respectively. Despite very rapid technological change (and related TFP growth) in these industries, these effects are not very large at the aggregate level due to the small share of these industries in total GDP in Europe.

More important for the aggregate productivity effect is the differential impact of ICT on the productivity growth in some typical ICT-using industries. Several industry

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[2] See McGuckin and Van Ark (2005) and **{** HYPERLINK "http://www.ggdc.net/dseries/totecon.shtml" **}**.

[3] See Jorgenson (2001), Gordon (2003), Jorgenson, Ho and Stiroh (2003) and Oliner and Sichel (2000, 2002)

[4] See Daveri (2002) and Timmer and Van Ark (2005).

level studies have pointed at the U.S. advantages from the use of ICT on productivity in service industries. Three major service industries account for most of the U.S. growth advantage, namely wholesale and retail trade and the financial securities industry.[5]

Hence not unlike the electric motor – and any other general purpose technology –, the economic impact of ICT partly derives from its production but also – and foremost – from its applications to business processes, and the production of new products and services.[6] The combination of the *macro-based evidence* that countries in Europe have somewhat lower investment in ICT with the *industry-level evidence* that intensive ICT users have shown slower productivity growth in Europe, suggests that one of the principal factors in explaining the slower European productivity growth is the failure to exploit the productivity effects from ICT.

In this paper our aim is to draw on historical parallels between the ICT era on productivity and earlier episodes of rapid technological change, namely the introduction of steam during the 19th century and that of electricity during the early 20th century. Most of the historical literature on the impact of GPTs on growth derives from experiences in the United Kingdom and the United States, largely because of the ample availability of historical data for these countries. But these two countries were typically at the frontier of the new technological paradigms in steam (UK) and electricity (USA). The experience of follower countries may be different and more strictly based on the diffusion of the GPT rather than invention itself. In a companion paper we have documented the evidence on the diffusion and productivity of steam, electricity and ICT in great detail for the Netherlands (Van Ark and Smits, 2005). With additional access to (admittedly more limited) data at macro and industry level for Finland, Sweden, the United Kingdom and the United States, we can test whether our main conclusions from the Dutch case also hold for other countries.

The paper proceeds as follows. In section 2 we review the long term evidence on the contribution of earlier GPT's to productivity growth from macroeconomic studies. Hence we look at adoption rates for steam and technology and discuss the possible relationship to productivity growth. In section 3 we adopt an industry perspective to look at the extent to which differences in productivity growth may be related to the technology diffusion. In section 4 we return to the recent evidence of the contribution of ICT to productivity growth, and discuss the parallels with the earlier GPT episodes to assess the implications for the future effects of ICT on productivity growth. In the

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[5] For the U.S., see Bosworth and Triplett (2003). For Europe, see Van Ark, Inklaar and McGuckin (2003) and Inklaar, O'Mahony and Timmer (2005).

[6] Bresnahan and Trajtenberg (1995)

concluding section (section 5) we discuss the role of non-technological factors interacting with the relationship between technology and productivity.

2. A Macro Perspective on Technology and Productivity in Historical Perspective

Research into the interrelatedness of technological breakthroughs and subsequent phases of economic growth goes back to the work of Kondratieff and has been revived by, among others, Landes (1969), Rosenberg (1982) and Freeman and Soete (1997). The latter two state that there are '... systematic interdependencies of myriad technical and organizational innovations. Like Hamlets' troubles, they come not single but in battalions. Process innovations, product innovations, organizational innovations and material innovations are all interdependent in mechanization, electrification or computerization.' (Freeman and Soete, 1997, p.31). If we accept the notion that radical new technologies arise in clusters which create new potential for growth, it is possible that long term changes in economic growth performance are somehow linked to changes in technological systems.

The first explicit and quantitative comparison of different phases of technological change originates from Paul David (1989, 1990) who drew an analogy between the introduction of electricity around the turn of the 19th century and the introduction of ICT during the 1970s and 1980s. David emphasizes the time lag between invention and productivity advances, as both the United Kingdom and the United States experienced a vigorous expansion of technology during the period 1900 to 1913, but a relatively slow growth of productivity. Only after 1913 a significant acceleration in productivity could be observed for both countries.

Steam diffusion

Recent research into the impact of steam on productivity growth reveals that even in the United Kingdom, the technology leader in the era of steam, the diffusion of this technology was rather slow and had a limited on productivity growth (Crafts, 2004a, 2004b). Watt's improved steam engine was patented in 1769, but it was only in 1830 that use of steam was at the same level as that of water power. The relatively low level of diffusion is reflected in the low share of steam engines in the capital stock. Around 1830 this share amounted to a mere 1.5% of the total capital stock in Britain (Crafts, 2004a, p. 341).

It was only during the 1850s, due to the development of high pressure steam power, that savings in coal consumption per hour resulted in a decline in the costs of steam power. Yet, even during the second half of the nineteenth century large parts of the British economy (such as agriculture and non-transport services) remained virtually untouched by steam.[7] It is therefore not surprising that the impact of steam technology on productivity growth has been quite modest. On the basis of growth accounting techniques, Crafts (2004a, 2004b) shows that TFP growth in Britain only showed a modest acceleration from 0 to 0.3 per year on average between 1760-80 and 1780-1831, and that productivity growth was steady but unspectacular at 0.75 for the remainder of the nineteenth century.

More or less the same trends can be discerned in countries on the European continent, which mainly depended on the import of steam technology from the U.K.. Although evidence on the diffusion of steam is lacking for most European continental countries, research into the diffusion of steam in the Netherlands reveals that traditional techniques based on wind and water energy prevailed because they proved to be cheaper for a considerable length of time (Smits, 1995; Smits et al., 2001). It was only after scale constraints were being removed that the use of steam became viable in the 1850s and 1860s. For example, the share of machines that are steam driven shows an increase from 13 per cent of the total number of machines in 1860 to 39 per cent in 1880 and then a rapid acceleration to 61 percent of total machinery in 1890. However, as adoption of steam has been faster for bigger machines than for smaller machines, an upper bound estimate suggests that steam power accounted for as much of 81 per cent of total power by 1890 (Van Ark and Smits, 2005). It should be noted, however, that the evidence of steam power which came relatively late to the Netherlands may not only be contrasted to the United Kingdom but also to other continental European countries. Due to the large share of agriculture, trade and personal services in GDP, relatively large segments of the Dutch economy were not affected by this new technology (Van Ark and Smits, 2005).

Electricity diffusion

The next technological paradigm produced much faster rates of adoption and higher rates of growth, especially in the United States. However, as pointed out by David (1989), there was still as much as 40 years between the major technological innovations in the field of electricity and the upsurge of labour productivity in the manufacturing sector, although the time-lag was much shorter than for steam (about 80 years). The first experiments with electricity were conducted by Galvani in the 1790s. In 1819 the phenomenon of electromagnetic induction was discovered which was the basis for the development of the dynamo in 1831. It was only after forty years that, due to a large series of incremental innovations, electricity could be used for

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[7] See also Nuvolari (2004). In the US the diffusion of steam also went at slow speed and left large parts of the economy unaffected. In the late 1830s only 5% of total power supply in industry was provided by steam. Even in key sectors of the first industrial revolution such as textiles, metals and machinery, the share of steam in the total supply of power amounted to only 25% in 1870 and 33% in 1910 (Edquist and Henrekson, 2004).

commercial purposes. Moreover, in the early years the diffusion of electricity may also have been hampered by the fact that parts of the economy were “locked” into steam technology. Only when electricity became a cheap alternative to other forms of motive power, electrical motors diffused rapidly through the economy.

Even in the United States (which was the productivity leader from the late nineteenth century onwards) electrical power still made a low contribution to total power in industry around 1900 (4%). This share grew almost exponentially in the following decades. Around 1910 the share of electricity accounted for 25% of total power, for 50% in 1919, 75% in 1929 and 87% in 1938 (Edquist and Henrekson, 2004).

Continental European countries showed approximately the same pace in adopting this new technology. In Germany, the Netherlands, Sweden and Finland the rate of electrification almost reached the U.S. level on the eve of World War I. The rate of electrification amounted to 22% in Germany 1906-1907, 25% in the Netherlands in 1912 and even 32% in Finland in 1913).[8] During the 1920s and 1930s the share of electricity in total industrial power supply converged to a level of more than 85% in all countries. Only in the United Kingdom electrification proceeded at a lower speed (10% of industrial motive power supplied by electrical motors around 1906/1907). This lower score can be ascribed to ‘lock in’-effects into steam technology, preventing British entrepreneurs to invest rapidly in new technologies.

Not only did electricity diffuse at more or less the same speed on both sides of the Atlantic, changes in the rate of labour productivity growth bear some similarities as well. Especially in the case of the productivity leader (the United States) the productivity improvement proved to be exceptionally fast. David and Wright (1999) show that U.S. labour productivity growth increased from 4.5% a year in the period 1909-1919 to 5.6% in 1919-1929. Using a growth accounting methodology with refined calculations of the contributions of factor inputs and total factor productivity, Gordon (1999, 2000) confirms the rapid acceleration in U.S. productivity after 1913. TFP increased at 1.6% per year on average during the whole period 1913-1972, compared to 0.6% from 1870-1913. However, with further adjustments for the composition of labour and capital and some adjustments for changes in retirements age of the capital stock, the acceleration is somewhat more modest, from 0.5% from 1870-1913 to 1.0% from 1913-1972.

In most other countries industrial labour productivity growth accelerated after 1913, and in particular during the 1910s and 1920s, which was the period in which the

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[8] Data on the rate of electrification are derived from Byatt (1979) for the United States and Germany, De Jong (2003) for the Netherlands and Jalava (2003) for Finland.

larger part of the manufacturing sector started to use electricity as its main source of power. Table 1 presents evidence regarding the labour productivity performance from 1870 to 1938. The growth figures for the period 1913-1938 indicate that productivity growth in most European countries was close to the growth rates in the U.S., with the exception of Belgium and the United Kingdom. It is remarkable that productivity growth was rather low in precisely those two countries which performed relatively strongly in the steam era. This can probably be explained from 'lock in' effects in old technologies.

Table 1: Average annual growth of labour productivity (GDP per hour worked), 1870-1938 (in %)

			of which	
	1870-1913	1913-1938	1913-1929	1929-1938
United States	1.9	2.1	2.4	1.5
Belgium	1.2	1.5	1.8	1.0
Finland	1.8	2.1	2.2	2.0
Netherlands	1.3	1.8	2.8	-0.1
Sweden	1.7	2.0	1.5	2.9
United Kingdom	1.2	1.2	1.4	0.8

Source: Maddison (1995).

In conclusion, it is very likely that in the United States as well as in Europe labour productivity growth was somehow related to the rapid diffusion of electricity in the industrial sector, and this is confirmed elsewhere in the literature. For example, for Finland, Myllyntaus (1991) has pointed out how electrification promoted the modernization of production processes. De Jong (2003) draws the same conclusion for the Netherlands.

But can the diffusion of electricity be solely responsible for the acceleration in growth? There are strong indications that the relationship is more complex than is often assumed for at least two reasons. Firstly, although the rate of electrification had reached more or less the same levels on both sides of the Atlantic in the 1930s, productivity increases in the U.S. remained above that of most European countries until the 1950s, after which the European postwar 'catching up' effect began to kick in. Secondly, already before the age of electrification, productivity growth in the U.S. was higher than in most (continental) European countries. Indeed David (1989) shows that only 25% of the differences in the growth rates of industrial labor productivity can be ascribed to the diffusion of electrical motors. This conclusion is in line with recent work of Gordon (2002) who argues that not only technology, but also political and historical factors explain the U.S. miracle during the "One Big Wave" of the period 1913-1972. From this perspective, the focus shifts from purely technological factors to the institutional context in which diffusion occurs. We return to this issue in the concluding section of the paper.

3. An Industry Perspective

In order to further clarify the effects of technology diffusion on productivity differentials, it is useful to also focus on the industry level. There are strong indications that not all key technologies are easily applicable in large segments of the economy. It is therefore useful to make a distinction between technologies which have been diffused in a limited number of industries and those which have been used economy-wide in most industries.

Diffusion of steam and electricity at industry level

Research into the diffusion of steam shows that, even in the case of Britain, only a limited number of branches were affected during the late 18th and early 19th centuries. Apart from shipping and railway transport, only textiles, mining and metals strongy benefited from the diffusion of steam. The diffusion may have been even less in countries with a low share of textiles, mining and metals in total industrial value added. For example, in the Netherlands the low levels of investment in steam technology are mainly due to the nature of economic specialization. From the late middle ages onwards the Dutch had been specializing in agriculture and trade, activities in which steam was not easily applicable. A comparison between Belgium (a classic example of a successful follower of Britain during the first industrial revolution) and the Netherlands (known for its late and slow diffusion) shows that the differences in number of horse power per inhabitant between the two countries is for 82% explained by differences in the output structure. In Belgium, the key sectors of the first industrial revolution contributed much more to GDP than in the Netherlands. But even in the Netherlands, steam power was used in manufacturing industries to different degrees. For example, in metal products and engineering rapidly the share of steam-driven machines was close or at 100% by 1890, whereas it was no more than 40% in other manufacturing industries such as food manufacturing, chemicals and wood working. (Lintsen et al., 1992)

Compared to steam, electricity is clearly much more of a general purpose technology as it was applicable in more sectors of the economy (see also section 2). Even though it was originally confined to lighting and in railways and tramways during the very early phase, it quickly spread throughout manufacturing and beyond to services.

The productivity effects from electricity

In section 2 it was already discussed that the impact of steam on productivity growth in the UK was limited to a few industries (Crafts, 2004a and b). The productivity impact of steam may have been even lower in the case of most other countries. For example, in the Netherlands, only 6 out of 26 industries scored labour productivity growth rates of more than 3 percent on average per year between 1860 and 1890. These industries, which accounted for only 16 percent of the total labour force, were all manufacturing industries including printing (7% per year), metals (4.2%), paper (4.2%), woodworking (4.2%), textiles (3.7%) and clothing & cleaning (3.1%). It should be stressed that these are labour productivity growth rates, which therefore include the effects from capital deepening.

In the United States, the diffusion of the electrical motor boosted productivity growth in large parts of the manufacturing sector. Growth rates of labour productivity were much higher during the period 1919-1929 than in the previous period (1909-1919) (David and Wright, 1999). This strong growth occurred in a wide range of sectors from the food-processing industries and the chemical industries (petrochemicals in particular) to the iron and steel industry. Especially the first two industries had witnessed rather low growth rates in earlier periods due to the fact that steam technology could not be applied on a large scale in these branches. It is interesting to note that the productivity increases in the electrical machinery industry in the U.S. remained relatively modest. This result confirms the importance of technology use to exploit the productivity effects.

Table 2 compares the productivity performance in the U.S. and three continental European countries. The European ‘followers’ also enjoyed widespread productivity benefits from electrification, showing patterns of development which closely resembled those of the United States. Large parts of the industrial sector in the Netherlands, Finland and Sweden enjoyed productivity benefits from this new technology. Since 1919 productivity growth in Sweden occurred throughout the industrial sector. Productivity growth increased most rapidly in food products, paper, chemicals and metal products. In Finland, productivity growth was strong across manufacturing with the exception of textiles. The Dutch economy showed larger differences between industries but in most cases productivity growth accelerated since 1913. On the whole, these data suggest that productivity growth became a much more general phenomenon since 1920, as is indicated by the declining standard deviations of industry growth rates.

It should be stressed, however, that authors have generally not found a clear significant statistical relationship between technological diffusion and productivity growth at the industry level. (Edquist and Henrekson, 2004). Hence some caution is required in directly relating technology diffusion to productivity growth at industry level.

Another way to look at the impact of technology diffsion originates from Harberger (1998), who suggests to look at the distribution of industry contributions to aggregate productivity growth. In case that only a few industries account for most of the aggregate productivity growth, Harberger speaks of a ‘mushroom’ type of growth. When industries contribute more equally to productivity growth, this may be referred to as a ‘yeast’ type of growth.

The results from David and Wright on total factor productivity growth in the aggregate manufacturing sector, reported above from 1919-1929, clearly suggest a ‘yeast’ type of growth. In contrast, Harberger (1998) himself, who focussed on the U.S. experience during the post World War II period found more of a mushroom-type growth process. In his view mushroom growth resulted from real cost reductions (which is one possible interpretation of TFP) which stemmed ‘from 1001 different causes’ (Harberger, 1998, p. 4-5). Comparing the two studies might indicate that the strong early impact of electricity across the economy relates to a surge in productivity, which was followed by a more ad-hoc process of different inventions and innovations during the mature period of technology use.[9] The growth experience during the latter period may also represent the petering out of the economy-wide diffusion process with some industries realizing growth effects through a continuous stream of new innovations, whereas in many other industries the new technology only created a once-for-all level effect.

Table 3 shows summary measures of the distribution of industry contributions to aggregate labour productivity growth in the Netherlands from 1860 to 2003, using historical national accounts for the period 1800-1921 in combination with historical data and current national accounts data from Statistics Netherlands (Smits et al., 2001; Van Ark and De Jong, 1996). The first measure in table eshows the aggregate productivity growth rate, which is the sum of all industry contributions. The second measure shows the cumulative labour share of industries with a positive contribution to productivity growth. The latter may be interpreted as a measure of the pervasiveness of growth.

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[9] The comparison between the David & Wright and Harberger studies is affected by the fact that former focuses on the manufacturing sector only.

Table 2: Labour Productivity Growth (GDP per person employed) in Manufacturing Industries, beginning of 20th century

	United States		Sweden			Finland		Netherlands			
	1909-1919	1919-1929	1913-1919	1919-1929	1929-1939	1901-1920	1920-1938	1900-13	1913-1921	1921-1929	1900-1938
Food	1.3	2.9	0.0	2.8	2.1	0.3	3.3	-1.0	-2.7	6.9	2.7
Textiles	0.2	4.1	-0.6	1.6	1.0	0.3	1.1	2.7	1.6	0.2	-1.0
Wood products	-1.8	2.1	0.0	0.3	1.1	0.2	2.7	11.3	-0.2	-25.6	6.3
Paper			-2.1	4.5	3.0						
-paper	1.3	5.7				3.0	7.9	2.6	-7.9	12.1	12.1
-printing	1.2	1.5				-1.2	4.0	2.8	2.7	6.7	9.4
Chemicals			-5.7	11.5	4.6	3.2	5.0	0.6	9.8	1.4	10.0
-chemical	0.2	4.0									
-petroleum	2.7	5.9									
Rubber&Leather			-2.5	0.1	1.0						
-rubber	6.2	6.7									
-leather	-1.1	3.3				-0.9	3.7	0.7	5.7	-5.2	6.5
Metal			-2.2	4.3	2.8	-0.7	4.2	-0.8	1.3	4.2	0.4
-iron and steel	2.8	4.4									
-non ferr. Metals	2.1	2.7									

Source: United States: David and Wright (1999), Sweden (Edquist and Henrekson, 2004), Finland (Hjerppe, 1990), Netherlands (Smits et al., 2000)

Table 3: Summary Characteristics of Distribution of Industry Contributions to Aggregate Labour Productivity Growth, Netherlands, 1860-2003

Technology Regime	Period	Aggregate annual labour productivity growth rate	Cumulative labour share of industries with positive contributions to productivity	Distribution of productivity gains between industries (0=equal; 1=unequal)*
Steam era	1860-1890	0.76	42	0.50
Initial electricity era	1900-1938	4.43	85	0.28
Mature electricity era	1977-1995	2.01	89	0.35
ICT era	1995-2003	1.04	71	0.49

* calculated as the ratio of the space between the curve representing the cumulative contribution of industries to aggregate productivity growth and the horizontal axis and the space between the diagonal and the horizontal axis.

Source: Van Ark and Smits (2005)

The third measure indicates the distribution of the productivity gains between industries. This distribution measure is closer to 0 when the pattern is more ‘yeast-like’ and closer to 1 when it is more ‘mushroom-like’.[10]

In line with the observations above, table 3 shows that the growth pattern was clearly more ‘mushroom-like’ during the steam era and more ‘yeast-like’ during the electricity area. In particular during the first few decades of the 20th century, productivity growth was more pervasive compared to the late 19th century. Moreover, productivity growth rates during this period were substantially higher than during the period 1860-1890. Electricity has probably been an important factor contributing to the improved productivity performance during the ‘big wave’ of the 20th century. Its application was widespread and went well beyond the manufacturing sector. The distribution of industry contributions during the ‘mature’ electricity era also looks somewhat more unequal during than during the ‘early’ electricity period. At the same time aggregate productivity growth is considerably lower in the second subperiod compared to the first.

Summary of the evidence for the pre-ICT era

The most important conclusions from the study of the two previous technology regimes are threefold. Firstly, the diffusion of electricity appears to have been faster and more more widespread across industries than for steam. The differences in adoption rates between countries are limited, and appear mainly due to differences in industrial structure. Secondly, the effect of electricity on productivity appears faster and more pervasive than for steam in both the 'leading' country (the U.S.) as well as in the following countries. Still, aggregate productivity growth rates have been higher in the U.S. than in Europe for the first half of the 20th century. Thirdly, although technology diffusion appears to be related to productivity growth, other factors such as the performance of the technology innovation system, other sources of comparative advantage, the functioning of markets and organizational changes also interact with productivity growth (see section 5).

4. Implications from the historical evidence for the ICT Era

The experiences with the most recent technology regime, related to information and communication technology (ICT), can now be put in historical perspective. To do so, we first look at the recent evidence on ICT diffusion and productivity at macro level, followed by a comparison of industry productivity performance with the earlier periods.

The diffusion of ICT

Recent data on ICT investment from the Groningen Growth and Development Centre show a clear upward trend in investment in ICT as a percentage of total investment in non-residential equipment.[11] This is a useful measure of the diffusion of the new technology. Table 4 shows that the ICT investment share in the EU-15 has been about half of that in the U.S.. It increased rapidly in both regions, but the gap between the two regions has not narrowed much during the past three decades. In some countries, however, ICT investment intensity is almost as high as in the United States, notably in some of the Scandinavian countries such as Sweden and Finland.

Strikingly, the ICT investment shares have fallen somewhat since 2000. It is important to examine which parts of the economy are responsible for this possible slowdown in technology diffusion. One possibility is that the collapse of the 'new economy' hype, referred to in the introduction, has mainly affected ICT producing industries in the hardware, software and telecommunication sector. Another more serious problem would be that the diffusion of ICT to its main users, notably market services such as trade, transport and financial services, has slowed down.

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[10] See Van Ark and Smits (2005) for a more detailed description of our application of the Harberger model to the Dutch data. See Inklaar and Timmer (2005) for a more detailed discussion of the type of summary measures presented in table 3.

[11] See **{** HYPERLINK "http://www.ggdc.net/" **}** and Timmer and van Ark (2005).

Table 4: ICT investment as % of total non-residential investment (current prices), 1976-2004

	1976	1995	2000	2004
Finland	5.8	25.8	26.3	27.6
Sweden	9.1	23.5	30.5	22.9
Belgium	7.7	18.0	24.2	20.1
Denmark	7.7	19.1	19.5	19.6
United Kingdom	4.8	21.7	25.0	18.4
Netherlands	6.3	13.1	17.7	17.1
Germany	8.1	13.3	17.4	16.1
Italy	7.6	14.8	16.1	15.5
Austria	6.9	12.4	13.7	13.1
Portugal	9.2	12.2	12.4	12.9
France	5.1	9.0	12.8	11.4
Greece	4.1	10.0	12.8	10.9
Spain	5.5	9.7	11.9	10.4
Ireland	3.3	9.6	14.2	8.8
European Union	6.8	14.3	17.6	15.2
United States	12.4	24.8	30.3	29.5

Source: Groningen Growth and Development Centre (**{** HYPERLINK "http://www.ggdc.net/dseries/growth-accounting.shtml" **}**)
Note: countries ranked in descending order of shares in 2004

For a limited number of countries (France, Germany, The Netherlands, United Kingdom and the United States) we have also information on ICT investment shares for individual industries, as obtained from the Groningen Growth and Development Centre. Table 5 shows that the ICT investment shares are generally highest in ICT production industries. Their behavior is rather volatile and there may be large differences in the composition of production of ICT goods.

With the exception of France, the investment shares in market services are generally about half of those in ICT production. However, as market services account for a much bigger share of the economy's output, their contribution to aggregate growth is likely to be much bigger than for ICT production. The U.S. ICT investment share in market services is much higher than in any of the European countries, and has shown a continuous increase since 1987, whereas the shares in European countries have increased more slowly or stalled. Indeed there is considerable evidence that U.S. service industries have applied ICT more intensively to improve delivery processes and create new services.[12]

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[12] See, for example, OECD (2004). McGuckin et al. (2005) present substantial evidence of rapid ICT diffusion in U.S. retail trade services compared to European countries.

Table 5: ICT investment as % of total non-residential investment by major industry group (current prices), 1987-2003

	1987	1995	2000	2003
France				
Market economy	10.2	11.5	16.0	14.5
ICT production	14.7	15.5	18.3	17.3
Market services*	14.1	14.6	19.6	18.2
Production industries**	4.4	5.6	8.9	8.3
Germany				
Market economy	13.8	14.0	17.7	16.5
ICT production	30.7	38.6	33.3	34.4
Market services*	13.0	12.9	17.8	17.1
Production industries**	9.6	10.1	13.3	11.5
Netherlands				
Market economy	13.9	15.8	21.1	22.7
ICT production	34.8	37.9	28.3	38.7
Market services*	16.2	17.9	23.9	25.3
Production industries**	7.4	8.3	11.6	11.6
United Kingdom				
Market economy	10.7	18.5	22.1	20.0
ICT production	20.8	47.1	50.8	36.5
Market services*	10.5	18.8	20.0	20.6
Production industries**	8.4	9.7	9.7	10.5
United States				
Market economy	21.5	26.1	34.0	34.3
ICT production	47.9	50.5	62.1	62.3
Market services*	24.1	29.1	35.9	38.0
Production industries**	11.3	13.8	16.3	16.7

* excluding ICT services: telecommunication services (ISIC 64)

** excluding ICT manufacturing: electrical and optical equipment (ISIC 30-33)

Source: Groningen Growth and Development Centre,
({ HYPERLINK "http://www.ggdc.net/dseries/iga.shtml" }).

The productivity effects of ICT use

Using a growth accounting decomposition technique, the impact from ICT on productivity for the EU and the U.S. can be compared (Timmer and Van Ark, 2005; Van Ark and Inklaar, 2005). In the light of the previous discussion it is most sensible to focus on the effect of ICT use in market services. This can only be done for the same countries as those mentioned above (namely France, Germany, The Netherlands, the UK and the U.S.) for which ICT investment data at industry level are available. Table 6 shows the percentage point contribution of market services to labour productivity growth in the aggregate market economy, as well as the percentage point contribution of the underlying sources of growth in market services, i.e., ICT capital, non-ICT capital, labour quality and total factor productivity.

Table 6: Contributions of Market Services and Underlying Sources to Market Economy Labour Productivity Growth, 1987-2003

	France	Germany	Netherlands	United Kingdom	United States
1987-1995					
Market Economy Labour Productivity Growth	2.4	2.6	1.7	3.0	1.4
Contribution of market services	0.5	0.9	0.5	1.0	0.5
of which:					
ICT capital deepening	0.2	0.3	0.3	0.3	0.4
Non-ICT capital deepening	0.2	0.3	0.2	0.5	0.1
Labour quality growth	0.1	0.1	0.1	0.4	0.2
Total factor productivity growth	0.0	0.2	-0.2	-0.2	-0.1
1995-2003					
Market Economy Labour Productivity Growth	1.8	2.1	1.4	2.6	3.5
Contribution of market services	0.1	0.3	0.6	1.3	2.0
of which:					
ICT capital deepening	0.3	0.4	0.6	0.5	0.8
Non-ICT capital deepening	0.0	0.1	0.3	0.4	0.3
Labour quality growth	0.1	0.0	0.1	0.1	0.1
Total factor productivity growth	-0.4	-0.2	-0.3	0.2	0.8

Source: Van Ark and Inklaar (2005)

Table 6 shows that the year 1995 is an important breakpoint in the comparative performance of the EU versus the U.S. Whereas U.S. productivity growth accelerated significantly, it slowed down in all European countries, and in particular in France and Germany. The U.S. growth resurgence since 1995 was to a large extent (almost 75%) due to a faster productivity growth in market services. This was considerable more than in the European countries, in particular in France and Germany where the contribution of market services even declined.

Faster labour productivity growth in U.S. market services appears partly due to a faster growth in ICT capital deepening in the U.S., but much more so due to an improvement in TFP growth. Since 1995 TFP has contributed as much to labour productivity growth as ICT capital deepening. ICT capital contributes much less to productivity growth in market services in all European countries, and TFP growth is even negative with the exception of the UK.

The superior performance of the U.S. market services sector is mainly due to three major service industries, namely wholesale and retail trade and the financial securities industry. Since 2000, the contribution of business services to aggregate productivity growth has also improved in the U.S.. In contrast, in European countries these service industries mostly show a productivity slowdown – or at best stability – since 2000.

Finally, as for the earlier GPT eras, it is interesting to look at the degree of 'yeastiness' or 'mushroomness' of productivity during the ICT era. Using the Harberger method, Table 7 shows the summary statistics for France, Germany, the Netherlands, the UK and the U.S. for aggregate total factor productivity growth rates in the market sector of the economy, the cumulative value added share of industries with a positive contribution to TFP growth, and the distribution of the productivity gains between industries (which is closer to 0 when the pattern is more 'yeast-like' and closer to 1 when it is more 'mushroom-like') is shown. In contrast to the measures shown in Table 3, the figures here refer to Total Factor Productivity (and not to labour productivity) and the industry shares are obtained on the basis of value added instead of labour.[13]

Table 7 shows that despite the decline in TFP growth in the continental European countries and the TFP acceleration in the U.S., the share of industries with positive TFP contributions has remained in between half and three quarters of value added in all cases. The continental European countries show a striking tendency towards a greater 'mushroom-type' of growth since 1995 as the distribution factor has increased well above 0.5, and even to 0.86 in the Netherlands. In contrast, the distribution factor in the UK and the U.S. has declined to around 0.5, which suggests a greater 'yeastiness' of growth compared to the pre-1995 period for the latter two countries.

How do the results for the ICT era compare to the earlier GPT phases? Table 3 in section 3, which shows Harberger summary statistics for labour productivity growth in the Netherlands, suggests a somewhat more 'mushroom' type process for the ICT era compared to the electricity age. For TFP, there is less information for historical comparisons except for the U.S.. But even the U.S. TFP rates for the most recent period cannot be directly compared with those for the early electricity phase, as no estimates are available beyond manufacturing. But if the diffusion of electricity in manufacturing during the early electricity phase can be compared with the diffusion of ICT in the service sector recently, the diffusion process was again clearly more 'yeasty' in the first period. However, for the the mature electricity phase during the

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[13] This is more in line with the original Harberger (1998) method. See Inklaar and Timmer (2005) for a more detailed discussion of these summary measures.

post World-War II period, Harberger (1998) suggests a more ‘mushroom’ type of growth pattern for the U.S. private economy.

Table 7: Summary Characteristics of Distribution of Industry Contributions to Aggregate Total Factor Productivity Growth in the Market Sector during the ICT-Era, 1987-2003

Country	Period	Aggregate total factor productivity growth rate	Cumulative value added share of industries with positive contributions to TFP growth	Distribution of TFP gains between industries (0=equal; 1=unequal)*
France	1987-1995	1.10	69	0.54
France	1995-2003	0.79	54	0.60
Germany	1987-1995	1.00	65	0.53
Germany	1995-2003	0.88	73	0.61
Netherlands	1987-1995	0.65	53	0.60
Netherlands	1995-2003	0.14	51	0.86
United Kingdom	1987-1995	1.18	65	0.54
United Kingdom	1995-2003	1.13	65	0.51
United States	1987-1995	0.42	52	0.73
United States	1995-2003	1.78	60	0.49

* calculated as the ratio of the space between the curve representing the cumulative contribution of industries to aggregate TFP growth and the horizontal axis and the space between the diagonal and the horizontal axis.

Source: Inklaar and Timmer (2005)

Strikingly, when comparing the U.S. estimates for the period 1987-1995 with those for 1995-2003, the trend for ICT appears to be opposite to that for electricity. Instead of moving from yeasty to mushroom growth, Table 7 suggests a trend from mushroom growth to a more ‘yeasty’ pattern of productivity growth. The distribution factor in the third column of table 7 clearly suggests a more equal distribution of productivity growth during the latter period. However, a more ‘yeasty’ process of growth cannot yet be observed for the European countries with the possible exception of the United Kingdom.

There may be various reasons for explaining the difference in distribution of productivity gains between the electricity era and the ICT age. Firstly, the technical impact of electricity may have been more widespread in first instance, followed by a broad range of innovations during the maturity phase, affecting sectors very differently. ICT application may have been more ‘mushroom’-like right from the beginning. The technical features of electricity and ICT deserve more research to better understand these differences. Secondly, the trend towards greater ‘yeastiness’ in the U.S. vis-à-vis greater ‘mushroom’ type growth in Europe during the ICT era may be related to non-technological factors that support or inhibit enterpreneurs to exploit the productivity advantages of the exploitation of ICT. The latter issue will be addressed in more detail in the concluding sector of this paper.

5. Concluding Remarks

Although the diffusion of ICT across industries seems somewhat slower in Europe than in the United States, ICT is widely applied across industries in the economy, in particular across a wide range of market service industries. The biggest difference between the EU and the U.S., however, seems to arise from the much smaller productivity effects from ICT. The fundamental question that arises is: is this difference simply due to a time-lag effect, as was also observed earlier for electricity and steam, meaning that Europe will catch up with the U.S. soon? Or is the EU-US differential due to other (non-technological) factors related to differences in knowledge infrastructure, general comparative advantages, the functioning of markets and organizational changes? The latter might mean that the U.S. advantage in ICT use over Europe will remain in the longer term.

Although non-technological factors also played a role in determining the productivity effect from electricity, technological factors such as the shift from shafts to wires in the production system may have dominated the diffusion process in those industries (Devine, 1983). In contrast, various authors have indicated the importance of non-technological factors in determining the productivity effect from ICT. For example, McGuckin and van Ark (2001) and McGuckin *et al.* (2005) argue that structural impediments in product and labour markets hamper the successful implementation of ICT across service industries in Europe. Limits on shopping hours and transport regulations and restrictive hiring and firing rules as well as other restrictive labour regulations make it hard for producers to organize their organizations to reap the full benefits from ICT. Furthermore, barriers to entry also limit competitive pressure. Eichengreen (2004) reports evidence on the payoff from IT capital formation, which appears greatest in countries where telecom infrastructure is most extensive, where financial markets are best developed, and where regulatory burdens are lightest. Gordon (2004), which focuses in part on the large contribution of retailing to productivity growth in the U.S., calls attention to regulatory barriers and land-use regulations in Europe that inhibit the development of large scale retail formats.

However, one must be careful not to embrace a simple story that is based only on excessive European regulation. For example, the more rapid take-off of wireless technology in Europe suggests that some regulation, for example, setting standards can be productivity enhancing as well. Gordon (2004) points at the different public and social choices in Europe concerning the dispersion of metropolitan areas, the promotion of public transport, the taxing of home ownership, etc.. These factors may determine different effects from ICT diffusion on productivity growth. Still, the question why most European economies have so far been unable to use ICT more productively on smaller scale operations remains an important issue for the research agenda.

Historical parallels teach some lessons and should temper exagerated expectations. But the present evidence on the steam and electricity, representing very different technologies with different applications and potential, cannot be imposed directly on the present experience. Also time will need to tell part of the story of the effects of ICT on productivity.

In sum, the most important finding in this paper is that technology diffusion and the productivity effects do not always follow the same pattern across industries, over time or across countries. The reasons for these differences are related to factors which often go beyond the application of the technology itself. A better understanding of these non-technological factors and a study of their impact in an historical perspective requires the further development of technology diffusion indicators at industry level, computations of related capital concepts and TFP, and quantitative analysis of institutional and policy variables in relation to TFP.

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