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ICT INVESTMENT AND GROWTH OF OUTPUT AND PRODUCTIVITY

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1. Introduction

Information and communication technology (ICT) may well be the most important modern technology and certainly a core element of the Knowledge-based Society. Expenditure on, production shares of and investment in ICT are rising, albeit at different rates of growth across member countries and between the EU and the USA. ICT has a significant impact on growth of GDP and productivity, although the scope of this impact and its direction are still subject to scientific controversy.

The consensus is growing that the "new" economy does have an economic impact. This is mirrored by Robert Solow who recently declared as obsolete his famous paradox that "we can see the computer age everywhere but in the productivity statistics"[1]. His change of mind was obviously based on the remarkable performance of the US economy, and on research on the growth and productivity impact of information and communication technology (ICT).[2]

In the 1990s, several causes combined to accelerate ICT diffusion and growth: technological change was coupled with massive price cuts, which made for a surge in digital technologies, that appears to be limited in its spread solely by the bottleneck created by the ability of individuals, enterprises and society to integrate these technologies in daily routine tasks. The Internet has spread much faster than other key inventions (thus it took electric light, electric motors and the internal combustion engine some decades to diffuse). An already existing predisposition of firms to exploit the opportunities of ICT, liberalisation of telecommunications and growth features of the Internet economy (economies of scale and network effects) together brought new vigour and eagerness to invest in new technologies. In the USA, business investment in computers and peripheral equipment, measured in real terms, jumped more than fourfold between 1995 and 1999 (see e.g. *Oliner – Sichel*, 2000). A rapid increase is also detectable in Europe, though not at the same pace as in the USA.

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[1] Cited in *Gordon* (2000)

[2] See for example *BLS*, 2000, *EU*, 2000, *Daveri*, 2000, 2001, *Gordon*, 2000, *Jorgenson – Stiroh*, 2000, *Kiley*, 1999, *OECD*, 2000, 2001, *Oliner – Sichel*, 2000, *Whelan*, 2000: studies which account for the positive impact of ICT on aggregate output and productivity growth.

Nevertheless, there are still divergent opinions of the overall importance of ICT for the economy, most notably on the productivity impact of ICT investment. The debate on the significance of the "new" economy primarily discusses the magnitude of the impact of ICT investment on economic development in non ICT producing sectors. Sceptics confine the impact of these developments to the ICT-producing industries. Recent research rather supports the view that the impact of ICT is felt in wider parts of the economy and thus has a positive effect on output and productivity growth, which in turn further raises the importance of this topic for economic policy.

The following chapters first report trends for ICT expenditure, production and investment and analyse country differences (Section 2). Then we discuss the methodological issues related to measurement of the output and productivity growth impact of information technology (Section 3), ICT expenditure and investment trends in Europe and the USA (Chapter 3). We present studies which quantify the impact of ICT on aggregate growth-cyclical effects and spillovers on labour. Chapter 5 provides a summary of findings thus obtained.

2. International trends in ICT spending and investment

2.1. ICT expenditure

The importance of ICT can be measured in terms of expenditure, production and investment. All are increasing, though at different rates in different countries. Expenditure in Europe seems to be more cyclical and, on average, lower than in the USA, although there are some noteworthy exceptions: Sweden and the UK spend as much on ICT as the USA.

ICT expenditure measures the diffusion of ICT goods and thus the absorption of ICT by businesses, private households and the government sector. Consequently, the readiness of firms to invest in these technologies and the willingness of private households and the government to use them impacts on the overall ranking of countries.

Country differences and overall gap

The available indicators on ICT spending reveal distinct differences in the level of expenditure between OECD countries. Sweden, and the UK in Europe, and Australia and the USA take the lead, spending about 8% per GDP for 1999, followed by the Netherlands and Denmark with expenditures close to 7%. France, Germany, Italy and Spain (the other large European countries) are grouped around or below the European average (1999: 5.6%). This European pattern is thus very heterogeneous: Small countries like Sweden, the Netherlands, Denmark and the UK exhibit ICT expenditure levels which are above or close to the United States. Germany, Italy and Spain – the large countries which significantly impact on average spending in Europe – are lagging behind. The overall result is that the expenditure share is 2.5 percentage points or nearly one third lower per GDP spending than in the USA.

Table 1: International comparison of ICT investment and production

	Share of ICT in business sector employment, 1998	Share of ICT in business sector value added, 1998	ICT expenditure as a % of GDP, 1998	ICT expenditure as a % of GDP, 1992-1999
Belgium	4.3	5.8	5.7	5.6
Denmark	5.1	-	6.7	6.6
Germany	3.1	6.1	5.1	5.3
Greece	-	-	5.1	3.8
Spain	-	-	4.0	3.9
France	4.0	5.3	5.9	5.9
Ireland	4.6	-	6.4	5.9
Italy	3.5	5.8	4.5	4.2
Netherlands	3.8	5.1	6.9	6.7
Austria	4.9	6.8	4.7	4.8
Portugal	2.7	5.6	5.1	4.5
Finland	5.6	8.3	5.7	5.6
Sweden	6.3	9.3	9.5	8.2
United Kingdom	4.8	8.4	9.0	8.1
EU 1)	4.0	6.4	6.0	5.6
Japan	3.4	5.8	6.2	6.0
USA	3.9	8.7	8.7	8.1
Switzerland	6.0	-	7.3	7.3
Australia	2.6	4.1	8.5	8.1
Canada	4.6	6.5	8.1	7.6

1) Weighted average (with GDP 1990), WIFO-calculations.

Source: *OECD*, 2001A, *WITSA,* 2000, WIFO calculations.

The European spending gap correlates with the smaller ICT-producing sector (see *McMorrow – Roeger*, 2000) but also comes from less dynamic spending by the government sector and private households. Australia demonstrates that a large ICT sector is not a prerequisite for high ICT expenditure: the ICT producing sector encompasses only 2.6% of overall business sector employment, even though Australia is among the big ICT spenders.

Expenditure follows business cycle in Europe

Throughout the 1990s, overall ICT spending increased both in Europe (+6.5% p.a.) and the USA (+7.8% p.a.), substantially accelerating in the second half of the decade (EU +3.7% p.a., USA 6.2% p.a., see Table 2). ICT expenditure increased far more steadily in the USA than in Europe (see Figure 1). The annual growth rates in Europe seem to be related to business cycle fluctuations, rising at above-average rates in periods of sound economic growth and stagnating or even declining in phases of low GDP growth. In the USA the overall growth performance and the growth of ICT expenditure are smoother but seem to be similarly coupled.

Box 1: Data availability and definitions of ICT expenditure

ICT expenditure measures the diffusion of computer hardware and peripherals, communications equipment and software. For Europe no official data are available, but figures are derived from surveys by private sources. The predominantly used data source is collected by IDC (*WITSA*, 2000). EITO also uses IDC data as a source and publishes its ICT expenditure data based on some adaptations of IDC data. Less frequently used sources are data from REED and Credit Suisse First Boston. It should be noted that ICT expenditure encompasses spending by businesses, private households and the government sector. To analyse its impact on output, growth and productivity investment figures are needed.

The data collected by ICD is gathered both at country level and from corporate headquarters[3]. ICD is the only available source for European countries which allows systematic cross-sectional comparisons for the 1992–1999 period. As ICD does not publicly release information as to the size and structure of its sample, the degree of comprehensiveness of the data set remains hard to gauge.

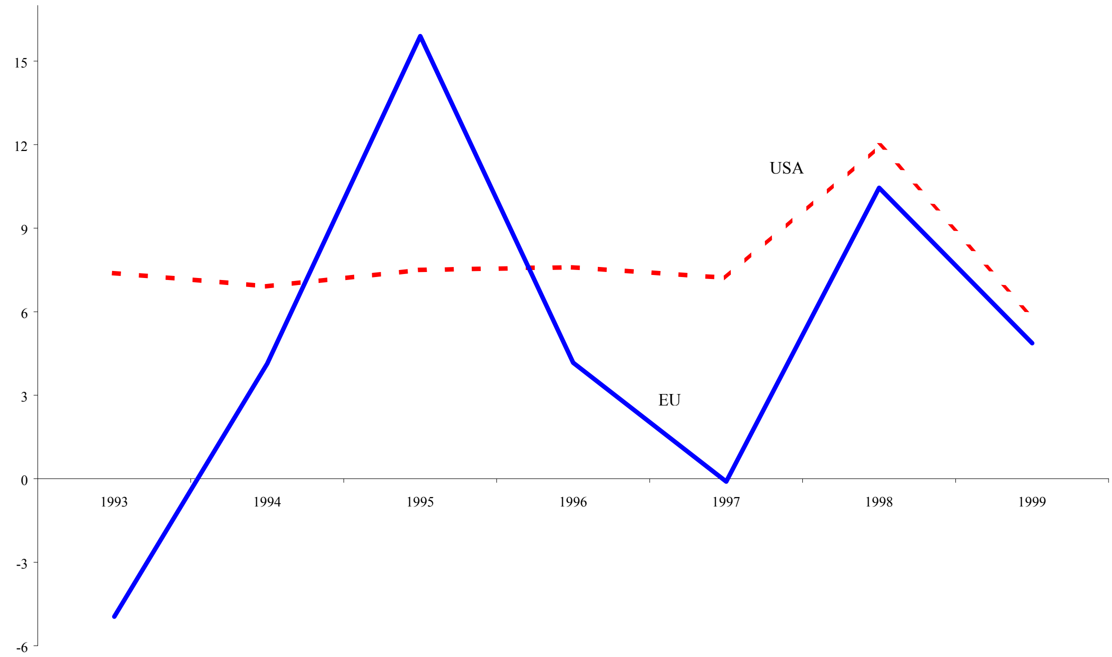
As these data sets are somewhat difficult to assess in their quality, OECD was motivated to extract ICT investment figures from the System of National Accounts 1993 (SNA 1993). This approach renders information for a limited number of countries as the SNA 1993 guidelines are not systematically implemented by all countries (see *OECD*, 2001B).

The situation in the USA is very different. The Bureau of Economic Analysis maintains the "Tangible Wealth Survey" which provides information on 57 distinct types of capital goods in current and chain-weighted dollars for 62 industries from 1947 through 1996. The distinct types of assets for each industry can be aggregated to calculate capital stocks for computer hardware and communications equipment. Software investment is not included in this survey, but BEA started to publish data on aggregate investment in software in its 1999 revision.

Source: *Stiroh*, 2001, *EU*, 2000, *WITSA*, 2000, *Oliner – Sichel*, 2000, *Landefeld – Grimm*, 2000.

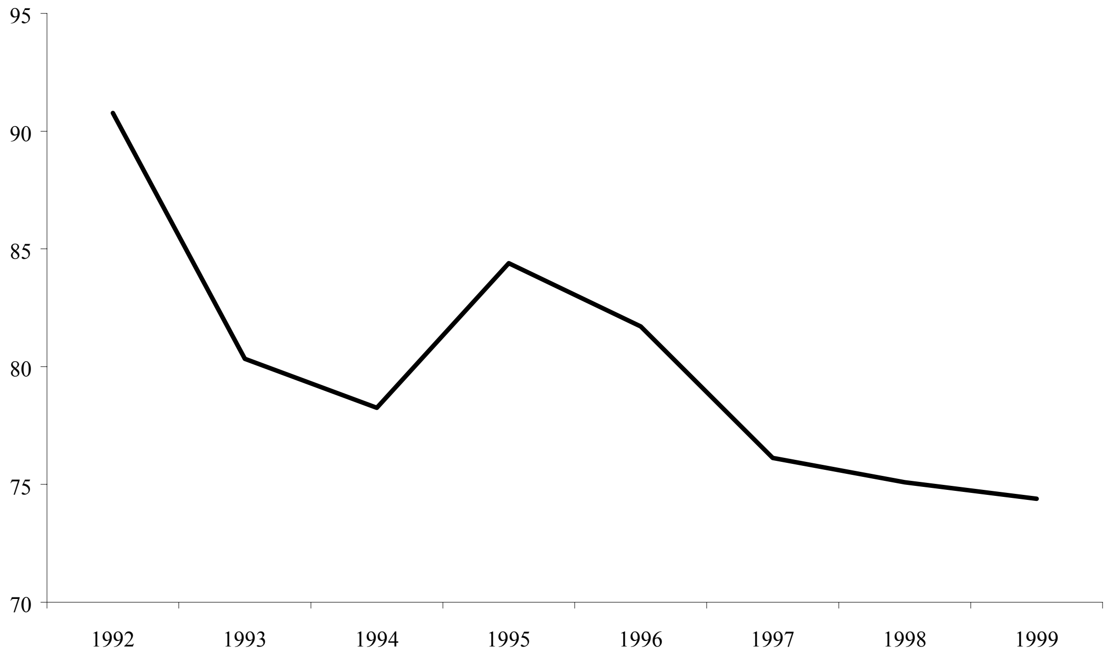
[3] IDC data collection takes place at country and corporate headquarters levels. Each local IDC office conducts interviews with local computer vendors and distributors. These data are compared with information from multinational vendors, collected and updated at IDC headquarters and regional research centres, and cross-checked with global vendor census data. Vendor data are then supplemented by user interviews and surveys (see *Daveri*, 2001).

Figure 1: Annual growth rate of nominal ICT expenditure in the USA and Europe



Source: *WITSA*, 2000, WIFO calculations.

Figure 2: European ICT expenditure in % of US expenditure



Source: *WITSA*, 2000, WIFO calculations.

The gap widens for EU total

The gap between ICT shares in Europe and the USA has widened since 1992 (exactly 2.3% in 1992 and 2.7% in 1999). Since, however, GDP in the USA is growing faster, the growth of ICT expenditure is more dynamic. Measured relative to US expenditure, European expenditure in ICT declined from 90% in 1992 to 75% in 1999 (see Figure 2).

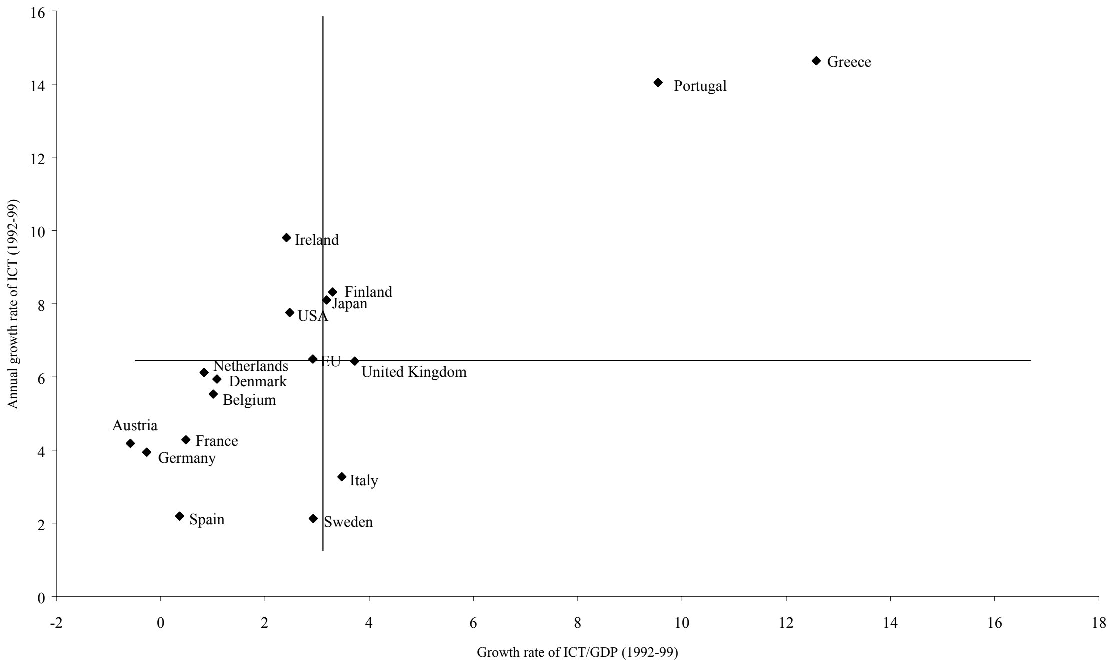
Table 2: Annual growth rates of ICT expenditure (1992–1999)

	Annual growth rate			Accerleration
Country	1992-95	1996-1999	1992-1999	second half - first half
Belgium	5.1	3.5	5.5	-1.5
Denmark	5.6	3.5	5.9	-2.2
Germany	4.3	2.8	3.9	-1.5
Greece	17.3	5.7	14.6	-11.6
Spain	-1.3	2.6	2.2	3.9
France	4.2	2.6	4.3	-1.6
Ireland	6.9	7.2	9.8	0.2
Italy	0.2	2.8	3.3	2.6
Netherlands	5.2	4.7	6.1	-0.5
Austria	3.8	3.3	4.2	-0.6
Portugal	18.2	4.6	14.0	-13.6
Finland	9.3	4.2	8.3	-5.1
Sweden	-1.3	3.0	2.1	4.3
United Kingdom	3.1	6.3	6.4	3.2
EU	3.5	3.7	6.5	0.2
USA	5.4	6.2	7.8	0.8

Source: *WITSA*, 2000, WIFO calculations

The most dynamic European countries with respect to ICT expenditure growth are Greece, Portugal Ireland and Finland (see Figure 3, Table 2 and 3). All of them increased their share of ICT expenditure per GDP in the 1990s and are now above or close to the European average (see Figure 2). The same applies – although at a lower level – to the Netherlands, Denmark, Belgium and the UK. In contrast, countries like Spain, Italy, Austria, France and Belgium on average showed below-EU-average growth of their ICT expenditures in the 1990s, and consequently a more or less stagnating share of GDP devoted to ICT. Germany and Austria even experienced a reduction of ICT expenditure per GDP.

Figure 3: Growth rate of ICT expenditures and ICT expenditures in % of GDP



Source: *WITSA* 2000, WIFO calculations

There are four countries which deserve special attention as they somewhat disturb rather systematic pattern: Greece, Portugal, Italy and Sweden. Sweden maintained its high level of ICT expenditure over the 1990s and thus raised ICT expenditure at about the same rate as GDP. It should be noted that the USA, which spend about as much on ICT as Sweden, had to increase its ICT spending level significantly to achieve this level of ICT per GDP. Italy also increased its ICT spending per GDP but with annual growth rates below the European average thus indicating that GDP growth was rather low. In Greece and Portugal, the high growth rates were driven by heavy investment in the telecommunications infrastructures – an investment which the majority of European countries had already made in the first half of the 1990s.

Overall, the acceleration of ICT spending between the first and second half of the 1990s is in Europe not as pronounced as in the USA. This is clearly visible at the country level (see Table 2): In the second half ICT expenditures grew faster only in UK, Sweden , France, Italy, Ireland and Spain thus contributing to the overall acceleration in Europe.

Table 3: ICT in % of GDP and growth rates for ICT in % of GDP

Country	1992	1995	1999	Differences 1999 - 1992	Annual growth rate of shares 1992-99
Belgium	5.5	5.5	5.9	0.4	1.0
Denmark	6.4	6.5	6.9	0.5	1.1
Germany	5.4	5.2	5.3	-0.1	-0.3
Greece	2.4	3.9	5.5	3.1	12.6
Spain	3.9	3.9	4.0	0.1	0.4
France	5.8	5.9	6.0	0.2	0.5
Ireland	5.5	5.9	6.5	1.0	2.4
Italy	3.7	4.2	4.7	1.0	3.5
Netherlands	6.7	6.6	7.1	0.4	0.8
Austria	5.0	4.7	4.8	-0.2	-0.6
Portugal	2.8	5.0	5.3	2.5	9.5
Finland	4.7	5.7	5.9	1.2	3.3
Sweden	7.6	7.8	9.3	1.7	2.9
United Kingdom	7.2	7.8	9.3	2.1	3.7
EU	5.2	5.6	6.2	1.0	2.9
Japan	5.7	5.4	7.1	1.4	3.2
USA	7.5	7.9	8.9	1.4	2.5

Source: *WITSA*, 2000, WIFO calculations.

Table 4: Nominal investment in ICT in % of GDP

	ICT investment/GDP			Total fixed investment/GDP		
	1992	1999	1999-1992	1992	1999	1999-1992
Belgium	2.12	2.59	0.47	21.29	20.99	-0.30
Denmark	2.04	2.72	0.68	18.14	20.97	2.83
Germany	1.74	2.17	0.43	24.04	21.29	-2.76
Greece	0.75	1.80	1.05	21.32	23.00	1.69
Spain	1.52	1.58	0.06	23.09	23.69	0.60
France	1.70	2.05	0.35	20.93	18.86	-2.07
Ireland	1.82	2.32	0.50	16.59	24.13	7.53
Italy	1.49	1.77	0.28	20.47	18.43	-2.04
Netherlands	2.23	3.09	0.86	21.32	21.47	0.15
Austria	1.61	1.89	0.28	23.50	23.65	0.15
Portugal	0.96	1.81	0.85	25.01	27.48	2.46
Finland	1.61	2.48	0.87	19.61	19.28	-0.32
Sweden	2.49	3.64	1.15	18.26	16.47	-1.79
United Kingdom	2.43	3.76	1.33	16.53	17.97	1.44
EU	1.81	2.37	0.56	20.72	21.26	0.54
USA	2.60	4.54	1.94	17.01	20.33	3.32

Source: *Daveri*, 2001, WIFO calculations for EU average.

2.2. ICT investment

ICT expenditure includes expenditure by private households and the government sector. Nevertheless it is the business sector which provides the relevant figures for estimating the ICT impact on output and productivity investment.[4]

Nominal ICT investment is about a third of nominal ICT expenditure. The main trends for investment are identical to those outlined above for ICT expenditure. US investment level is higher, Europe's investment is growing cyclically and declining relative to the USA. However, none of the European countries – and this is contrast with ICT expenditure – reaches the US level for ICT investment. The latter may be due to the different weighting of the components (hardware, software, communications equipment) in the calculation of ICT investment for Europe.

The rapid diffusion of information technology is mirrored in the rising share of ICT investment goods in non-residential gross capital formation in the business sector. In 1999, about one third of all investments in Finland and the US business sector were devoted to ICT goods (see Table 5, *OECD*, 2001A). In Australia, this share encompassed about one fifth of business sector investment. In France, Germany, Italy and Japan – the other countries in the sample – the level of investment in ICT was about half as large as in the USA and in Finland. The rapid increase of ICT investment – which is discernible in all countries – accounted for about 50% of the rise in investment in the US business sector.

This eagerness to invest in the new technology was somewhat surprising given the long-lasting discussion of the "productivity paradox" which "complains" about the missing productivity impact of investment in computing equipment. Managers obviously had a different perception of the impact of digital technologies on output and productivity growth. The dramatic drop of prices (see Box 4.3) for these assets supported the trend and favoured substitution between different types of capital goods.

[4] *Daveri* (2001) calculates investment data for Europe based on a comparison of WITSA figures for the US with the official investment data from the Bureau of Economic Analysis (BEA). The relationship between WITSA expenditure and BEA figures for investment on hardware, communications equipment and software is used to calculate the share of business expenditure/investment in the overall figure. Under these assumptions, hardware investment in the US is 58.6% of total hardware spending as reported by WITSA, communications equipment is 31.6% of WITSA expenditure and software investment (including own-account software) is about 212.5% of the WITSA software item, respectively. These coefficients are then multiplied by the corresponding WITSA spending items for EU countries to obtain nominal IT investment spending data for the 1992–99 period.

Table 5: Nominal share of investment in ICT in % of total investment of the business sector

		Germany	France	Italy	Finland	Unweighted average 4 EU countries	Japan	USA	Australia	Canada
IT equipment	1980	4.1	2.5	4.0	2.6	3.3	3.3	5.1	2.2	4.5
	1990	5.3	3.3	4.2	4.5	4.3	3.8	7.0	5.4	5.8
	1995	4.6	3.5	3.5	5.5	4.3	4.6	8.7	8.0	7.9
	1999	6.1	4.0	4.2	3.8	4.5	5.2	8.5	6.5	7.6
Communications equipment	1980	4.9	3.3	3.9	4.0	4.0	3.4	7.1	4.4	3.2
	1990	5.0	3.7	5.7	4.8	4.8	4.0	7.5	3.9	4.0
	1995	4.2	4.4	6.7	13.0	7.1	5.3	7.3	5.2	4.4
	1999	4.3	5.8	7.2	20.3	9.4	6.9	8.2	5.6	5.3
Software	1980	2.8	2.4	1.7	2.9	2.5	0.6	3.0	1.0	-
	1990	3.7	2.8	3.8	5.5	4.0	4.7	8.0	4.4	-
	1995	4.5	3.6	4.3	11.6	6.0	6.0	10.1	6.1	-
	1999	5.7	6.2	4.9	11.9	7.2	5.7	15.0	8.7	-
ICT equipment and software	1980	11.8	8.2	9.6	9.5	9.8	7.2	15.2	7.6	-
	1990	14.0	9.8	13.7	14.9	13.1	12.4	22.5	13.7	-
	1995	13.3	11.5	14.4	30.0	17.3	15.9	26.1	19.3	-
	1999	16.2	16.0	16.3	36.0	21.1	17.9	31.7	20.8	-

Source: *OECD*, 2001B.

There are considerable differences between countries in investment and uptake of ICT, partly due to policy differences. Competition is particularly important. Sufficient competition helps to lower costs, thus encouraging ICT investment and diffusion. Policy plays an important role in ensuring sufficient competition, e.g. through regulatory reform, effective competition policy and the promotion of market openness at the domestic and international level. Regulatory reform of the telecommunications sector is of particular importance, as the use of ICT in networks relies to a considerable extent on the costs of communications (*OECD*, 2001A). Consequently, significant effects of liberalisation in 1998 should be felt in the years not included in the data.

Capital stocks and investment contain ever higher shares of ICT

Two more indicators underline the increasing importance of ICT. Firstly, the capital stocks of all ICT components have risen much faster than those of capital goods in general. The capital stock of communications equipment and software increased by about 10% annually in Europe, that of hardware by about 30% (unweighted averages). Compared to the USA, growth rates for capital stock of communications equipment were higher in Europe, about the same for hardware and lower for software. Secondly, the share of ICT investment in total investment increased substantially, most notably that for hardware. Today, 32% of total business investment is in ICT in the USA, after 15% in 1980. In Europe it rose for large countries from 10% to 16%, and skyrocketed in Finland to 36%.

Table 6: Growth of ICT and aggregate capital stocks, 1991–99

	Communications equipment	Hardware	Software	All capital goods (business sector)
Belgium	10.3	27.9	8.4	3.0
Denmark	9.8	26.6	11.7	2.9
Germany	13.5	29.6	13.3	2.6
Greece	16.4	42.6	16.1	2.7
Spain	12.6	25.2	7.2	4.0
France	11.4	24.0	10.3	2.3
Ireland	13.2	28.8	15.9	3.2
Italy	11.1	23.6	5.1	2.7
Netherlands	9.9	32.1	14.0	2.3
Austria	9.7	29.9	12.4	4.3
Portugal	24.6	43.2	11.1	4.5
Finland	8.8	23.8	9.7	0.5
Sweden	5.2	25.0	9.6	2.1
United Kingdom	7.8	31.6	14.3	2.9
EU	11.2	27.6	10.8	2.7
USA	4.9	31.2	17.4	2.6

Source: *Daveri*, 2001, WIFO calculations.

3. Measuring the impact of ICT investment

Investment in information technology impacts on economic output and productivity growth through three separable channels (see *Stiroh*, 2001, *EU*, 2000, *McMorrow – Roeger*, 2001):

1. **Growth of labour productivity:** The primary effect of ICT use should be an increase in labour productivity through additional capital formation (ICT capital) which raises the productivity of labour (i.e. capital deepening).

2. **Increase in multi-factor productivity:** Technological progress allows production of improved capital goods at lower prices, thus raising multi-factor productivity growth in the sector producing IT goods. The magnitude of this effect depends on both the speed of technical progress and the share of the ICT sector in overall production.

3. **Spillovers:** ICT investment induces embodied technological change, thus increasing multi-factor productivity growth outside the IT sector, generating production spillovers or externalities.[5]

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[5] *OECD* (2001A) finds evidence that there is also a strong positive correlation between indicators of ICT use (e.g. numbers of secure servers, Internet host density, PC density and Internet access costs) and the pick-up in MFP growth

Box 2: The neoclassical growth-accounting methodology

The neoclassical growth-accounting methodology uses a production function to relate inputs and outputs. Variations in output are accounted for by changes in production inputs, i.e. capital and labour. The proportion of output that cannot be attributed to inputs is called multi-factor productivity (MFP) and catches all output increases which are due to technological and organisational changes that are not explained by changes in inputs. Starting from the results of this growth-accounting exercise, the calculation of labour productivity is straightforward: output and input variables in the production function are divided by the labour input.

Measurement of the impact of information technology on economic development requires that the capital input is broken down in ICT and non-ICT capital. Many studies further disaggregate information technology into computer hardware, software and communications equipment. The overall growth contribution from the use of information technology capital equals the sum of the contributions from computer hardware, software, and communication equipment.

In the standard growth-accounting framework, the real growth rate of each input is weighted by that input's income share[6]. Both components of this simple multiplication deserve some attention:

1. First, the nominal capital stock of the input is measured to estimate income shares. This stock earns a gross rate of return that must cover the real net rate of return common to all capital, together with taxes and the loss of value which this input suffers over time (capital service). The product of the gross rate of return and the nominal productive stock equals the nominal income flow generated by this input. This is divided by the total nominal income for the economy to obtain the desired income share. This method is applied to measure the income share for each type of capital. The income share for labour inputs is then measured as one minus the sum of the income shares for the various types of capital (see for example *Oliner – Sichel*, 2000).
2. An important issue in every growth-accounting exercise is the correct measurement of real prices for ICT. There are few sectors in the economy where technological progress increases the performance of goods and services at such a pace as ICT. Taking ICT components at nominal prices would ignore these huge performance increase of ICT by itself and, of course, when these goods and services are applied in the economic process. In order to cope with this situation, hedonic price indices have been developed. These are statistical tools for developing standardised per-unit prices for goods, such as computers, whose quality and characteristics are changing rapidly. In designing hedonic price indices, a statistical model is used that makes a regressive estimate of the prices of a basket of goods based on a set of their qualities or characteristics. Using the statistical relationship between observed price changes and changes in the characteristics and qualities of goods, a hedonic price index is then developed that measures relative price changes while holding quality and characteristics constant (*Landefeld – Grimm*, 2000).

To sum up, the main forces determining the growth contribution of ICT and its components are the size of the capital stock, its growth rate, the usage costs of capital and the development of prices for ICT goods.

The growth-accounting approach thus rather "mechanically" attributes shares in output growth according to the size of the input factor, its growth rate and – in case of capital – the capital services generated by this input. Growth-accounting techniques assume the result when factor shares proxy for output elasticities and do not estimate econometrically the contribution of inputs to output or productivity growth. Growth-accounting therefore provides a valuable and well-tested means for understanding the proximate sources of growth, namely accumulation of capital and labour, plus multi-factor productivity. In particular, this framework does not model the underlying technical improvements that have driven capital accumulation. In this sense, the neoclassical framework provides a superficial explanation of growth. Additional evidence produced by alternative methods is necessary to validate these results (see *Oliner – Sichel*, 2000, *Stiroh*, 2001).

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in the second half of the 1990s. Countries that have experienced a substantial pick-up in MFP growth in this period typically have a higher diffusion of ICT technologies, as well as lower costs of ICT technologies.

[6] Using the log values of the variables.

The distinction between these forces is quite difficult and subject to severe measurement problems. Measurement of the impact of ICT on growth and productivity has a long history, and different methods are applied at the aggregate, sectoral and firm levels. The recently published studies on the impact of ICT investment on aggregate output growth – which will be at the centre of our interest – use the neoclassical growth-accounting methodology as pioneered by *Solow* (1957). Studies on the sectoral or firm level usually apply econometric models based on production functions to assess the impact of ICT use (for a survey see *Brynjolfsson – Yang*, 1996, *Brynjolfsson – Hitt*, 2000, *Stiroh*, 2001).

4. The economic impact of investment in ICT

4.1 The mainstream results for the USA and Europe

Despite all the differences in the approach and all the problems with the data, there is unanimity that ICT really does significantly contribute to growth and productivity, that this impact is larger in the USA than in Europe, and also greater in the second half of the 1990s relative to the first.

The US economy grew rapidly in the 1990s, especially in the second half. The European economy also managed to accelerate growth rates but at a lower level. Most studies[7] underline that "there is no single factor that explains the divergence in growth performance. OECD countries that have improved performance in the 1990s have generally been able to draw more people into employment, have increased investment, and have improved multi-factor productivity (MFP). The European Union has experienced a more modest acceleration in labour productivity growth of ¼ of a percentage point over the same period to reach an annual average rate of 2% for the second half of the 1990s" (*Mc Morrow – Roeger*, 2001).

One obvious candidate for explaining the strong performance of the US economy is the rapid diffusion of information technologies which was fuelled by a steep decline in prices for ICT goods. The mainstream result of the studies[8] is that ICT investment explains about 0.4 to 0.5 percentage points in the first half and 0.8 to 1 percentage point of output growth in the second

[7] *OECD*, 2000: Studies over the past years (*Schreyer*, 2000, *Scarpett, et a.l*, 2000, *OECD*, 2000a, *Federal Reserve Board*, 2000) have furnished evidence.

[8] *BLS*, 2000, *EU*, 2000, *Daveri*, 2000, 2001, *Gordon*, 2000, *Jorgenson – Stiroh*, 2000, *Kiley*, 1999, *OECD*, 2000, 2001, *Oliner – Sichel*, 2000, *Whelan*, 2000)

half of the 1990s (see Table 7). Thus the importance of ICT for economic growth more than doubled compared to the first half of the past decade[9].

For EU member countries there are basically two estimates available on the growth impact of ICT investment (*EU*, 2000, *Daveri*, 2001). *OECD* (2001B) presents estimates for four European countries as part of a sample of eight countries. Estimates for European countries generally calculate a lower contribution of ICT to output growth. On average, about 0.5 to 0.6 percentage points of output growth in Europe are due to ICT. The estimates in the two available studies for the full sample exhibit marked differences (see Table 8). *Daveri* (2001) finds a considerably larger ICT growth contribution in the first and second half of the 1990s although the increase between the two periods is not as distinct as in other studies. His estimate for the growth contribution of ICT in the USA and some of the European countries is substantially higher than in other studies.

The distinct difference in the contribution of information technology within Europe and the USA respectively can be seen in the results of *Daveri* (2001) and the *EU* (2000). Both in the 1990s as a total and in subperiods none of the European countries had achieved a growth contribution of ICT investments that is comparable to the USA (see Table 8). In the USA, about 0.9% percentage points of output growth in the 1990s are attributed to ICT investments. The UK achieved 0.76 percentage points due to investment in ICT and is thus the European country with the highest contribution. Other big European ICT investors like the Netherlands, Sweden, Finland and Ireland are well below this level but still ahead of the remaining European countries which reveal rather homogeneous ICT growth contributions of around 0.3 to 0.5 percentage points. The European average ICT growth contribution is dominated by low (and sometimes even declining) ICT growth contributions in countries like Germany, France, Italy and Spain.

The difference in the results between Europe and the USA is somewhat lower in the OECD estimates which used official data from the System of National Accounts. France, Germany, Finland and Italy were the European countries in the sample. Again, the ICT growth contribution for the European countries was lower than in the USA, but the difference was not as marked as in Daveri's estimates. In the second half of the 1990s, Finland's ICT growth contribution (0.58 percentage points) was at about two thirds of the US level of 0.88 percentage points. In France, Germany and Italy, ICT investment contributed about 0.3 percentage points to

[9] The major exception is *Kiley* (1999): He estimates a negative growth impact of ICT which is due to adjustment costs associated with the implementation of ICT. In his framework the effect of ICT would turn positive once

output growth in this period. It is noteworthy that the ICT growth contributions in the 1995–1999 period doubled in the USA and Finland. In France and Italy they increased by about 50% but remained almost stagnant in Germany.

Compared to the USA, Europe seems to lose 0.3 to 0.5 percentage points of economic growth. The major cause for the lower contribution of ICT to aggregate growth in Europe is lagging investment in ICT. Other factors to affect the outcome of these growth-accounting exercises (price measurement and usage costs of capital) were assumed to be similar to the USA and thus cannot account for growth differences (see *Daveri*, 2001, *EU*, 2000)[10].

Table 7: ICT growth contribution

	Country/Region	Period	Software	Hardware	Communications Equipment	Total ICT
OECD, 2001	USA	1990-95	0.14	0.20	0.08	0.42
		1995-99	0.27	0.49	0.13	0.89
Jorgenson & Stiroh, 2000	USA	1990-95	0.15	0.19	0.06	0.40
		1995-99	0.21	0.49	0.11	0.81
Oliner and Sichel, 2000	USA	1991-95	0.25	0.25	0.07	0.57
		1996-98	0.32	0.59	0.15	1.06
Daveri, 2001	EU	1991-99	0.14	0.28	0.13	0.56
EU, 2000	EU	1992-94	-	-	-	0.27
		1995-99	-	-	-	0.49

Table 8: ICT growth contribution in Europe

	1992-94	1995-99	Accerleration second half - first half
Belgium	0.35	0.60	0.25
Denmark	0.22	0.38	0.16
Germany	0.25	0.41	0.16
Greece	0.12	0.21	0.09
Spain	0.19	0.39	0.20
France	0.24	0.42	0.18
Ireland	0.84	1.91	1.07
Italy	0.25	0.42	0.17
Netherlands	0.41	0.67	0.26
Austria	0.24	0.41	0.17
Portugal	0.25	0.55	0.30
Finland	0.31	0.63	0.32
Sweden	0.30	0.68	0.38
United Kingdom	0.35	0.64	0.29
EU	0.27	0.48	0.21

Source: *Daveri,* 2001, *EU*, 2000.

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investment in ICT will be reduced or halted. Then adjustment costs would not cancel out the positive impact of ICT on output growth.

[10] The major forces determining ICT growth contribution are the size of the capital stock, its growth rate, the usage costs of capital and the development of prices for ICT goods.

Box 3: The growth contribution of hardware, software and communications equipment

Most growth-accounting studies calculate capital stocks for computer hardware, software and communications equipment and assess the impact of these components of ICT investment separately. This renders information on the relative growth impact of the different forms of information technology. In the USA, the largest contribution to output growth stems from hardware investments[11]. In the second half of the 1990s, hardware investment raised output by 0.5 to 0.6 percentage points (see Table 7). Software contributed about 0.2 to 0.3 percentage points and communications equipment about 0.1 to 0.15 percentage points. Hardware and communications equipment doubled their impact in the second half. The increase was slightly lower for software. The evidence available for Europe (*Daveri*, 2001) estimates growth contribution of hardware at about half the US level (0.24 percentage points – weighted average based on *Daveri*, 2001), slightly lower for software (0.13) and at the same level for telecommunications equipment (0.12). Thus, lower hardware spending seems to be the major cause for lower ICT capital stocks in Europe and consequently lower contributions of ICT to overall growth.

The growth impact of hardware investment is to a significant extent due to the use of hedonic indices to deflate prices for ICT equipment (see *Schreyer*, 2001, Box 4.1). For example, quality-adjusted prices for computers and peripherals have been falling at about 24% annually (*Landefeld – Grimm*, 2000). This is much faster than for software and communications equipment. Research in Germany (*Moch*, 2001) more or less confirms the rate of price decline as applies in the USA for computer hardware.

Rapidly falling prices for information technology push up the growth rate of real capital stocks (see Table 6), thus allocating a larger part of overall growth to information technology. As demonstrated by *Schreyer* (2001), hedonic price measurement may in some countries double the magnitude of growth effects for hardware investments.

Is it productivity in ICT production or do spillovers exist?

While the general impact is assessed in a rather similar manner, the relative importance of productivity growth within the ICT sector relative to spillovers from ICT to other industries is far from resolved.

Higher labour productivity in the USA is mainly due to capital deepening (0.1 to 0.33 percentage points) and multi-factor productivity growth (0.3 to 0.9 percentage points). Both categories are substantially influenced by IT usage and production. The positive impact of ICT-related capital deepening is present in all studies cited in Table 9 and emphasises the direct, labour productivity increasing impact of ICT investment. The controversial issue is the effect of

[11] Firm-level evidence supports this view: these studies suggest that computers did have am impact on economic growth that is disproportionately large compared to the size of the capital stock or investment, and that this impact is likely to grow in the future (*Brynjolfsson – Hitt*, 2000).

non-ICT-producing sectors on multi-factor productivity growth. *Gordon* (2000) attributes almost all of the acceleration of multi-factor productivity growth to the ICT-producing sectors (see also Box 4.3). Although *Jorgenson – Stiroh* (2000) and *Oliner – Sichel* (2000) calculate about the same effect for ICT-producing sectors, they still find a substantial contribution from non-ICT-related sectors (0.4 to 0.5 percentage points) to multi-factor productivity growth. Thus they support the view that ICT use has had positive effects in non-ICT-producing industries.

Table 9: Sources and alternative explanations of the acceleration in labour productivity

	BLS (2000)	Gordon (2000)	Jorgenson & Stiroh (2000)	Oliner &Sichel (2000)
Average Labour Productivity, 1995-99	2.30	2.75	2.37	2.57
Average Labour Productivity, 1973-95	1.39	1.42	1.42	1.41
Acceleration	0.91	1.33	0.95	1.16
Capital Deepening	0.10	0.33	0.29	0.33
IT-Related	0.38	n.a.	0.34	0.50
Other	-0.31	n.a.	-0.05	-0.17
Labour Quality	0.06	0.05	0.01	0.04
TFP	0.90	0.31	0.65	0.80
IT-Related	n.a.	0.29	0.24	0.31
Other	n.a.	0.02	0.41	0.49
Cyclical Effect		0.50		
Price Measurement		0.14		

Source: *Stiroh*, 2001.

Gordon (2000) argues that recent productivity growth is not based on ICT use but that the increase in labour productivity is a normal, cyclical acceleration as the economy expands[12]. He therefore subtracts a term to account for this cyclical effect and makes some adjustments for price measurement. These adjustments eliminate the contribution of non-ICT-producing sectors to the acceleration of multi-factor productivity growth (see Table 9). He repeats this exercise for subsamples of the economy by either excluding the ICT-producing industries or the manufacturing sector and thus arrives at a reduction of multi-factor productivity in the remaining parts of the economy. His interpretation of these findings is that there is no such thing as a "new" economy but that the massive ICT investments outside the ICT-producing sector

[12] In a fast growing economy the labour input is quasi-fixed in the short run. The labour force adapts to rising demand by working harder and sometimes longer (variable utilisation and resource allocation effects) as inputs are not immediately increased in a business cycle upturn. Consequently Labour productivity rises although the basics of the economic process are unchanged. The argument that ICT is behind productivity increases in the second half of the 1990s is diminished by this longstanding observation of a positive relationship between productivity and growth. Even without increased ICT investment productivity would have increased in the upturn of the 1995 to 1999 period (see *Gordon*, 2000).

may be focused on unproductive activities like market share protection, duplication of existing operations, or on-the-job consumption and thus have a negative productivity impact[13].

This controversy cannot be decided at the aggregate level but needs evidence either at sectoral or firm level. If there is a positive impact of ICT investment it should be visible in the largest users of ICT investment goods in the services sector: communications, wholesale and retail trade, finance, insurance and business services (see *OECD*, 2001A). Most of these service sectors have exhibited rather weak productivity growth which is partly related to well-known measurement problems of the output in service industries. It is – as *Brynjolfsson – Hitt* (2000) argue – most unlikely that the productivity of the US banking sector has decreased, given its high spending on ICT and the observable improvement in service diversity and quality.

Consequently, limited acceleration of productivity growth in non-ICT producing industries was found in a number of papers (see *Brynjolfsson – Hitt*, 2000, *Brynjolfsson – Yang*, 1996 for studies at firm level). These studies support the hypothesis that productivity growth is confined to ICT-producing industries but did not find a negative impact of ICT usage in other industries. Recent studies are more optimistic on the impact of ICT investment. *OECD* (2001A) found evidence for a positive productivity impact of ICT in the ICT-using sectors. Denmark, Finland, Germany, the Netherlands and the United States have experienced an increased contribution of ICT-using services to labour productivity growth while industries which are less intensive users of ICT did not increase their contribution to labour productivity growth. This positive effect on labour productivity growth was confined to the second half of the 1990s. To be successful, investment has to be coupled with organisational changes and upskilling of the labour force (see *Bresnahan – Brynjolfsson – Hitt*, 2000). Consequently, it is not surprising that recent studies more frequently find positive impacts of ICT usage than older ones.

[13] There are more critical comments which will not be discussed in detail: *Roach* (1998) argues that much of the productivity growth is due to the understatement of actual hours worked, which leads to an overstated productivity growth, as the white-collar workweek expands faster than the data measure. *Kiley* (1999) assumes large adjustment costs that create frictions which cause investment in ICT capital to be negatively associated with productivity, at least in the short run.

Box 4: The productivity impact of ICT-producing industries

The argument that rapid productivity increase in the ICT-producing industry contributed substantially to overall productivity growth is not controversial but rather supported by most of the studies cited above. OECD studies demonstrate that ICT-producing industries have made significant contributions to labour productivity growth in several OECD countries (*Scarpetta et al.*, 2000). Some clue to the importance of ICT on productivity growth can be derived from analysing the sectoral productivity performance and the contribution of each sector to overall productivity growth.

Consequently, the contribution of the ICT sector to overall economic performance depends on the rate of productivity growth, on the size of the sector and the specific composition of goods produced. *OECD* (2001A) demonstrates that the machinery and equipment industry had considerably higher productivity growth than the manufacturing sector overall in most of the eleven countries analysed. Labour productivity growth was much higher in the two key ICT-producing sectors, i.e. the electrical and optical equipment industries. In general, the manufacturing part of the ICT sector has a considerably higher productivity growth than manufacturing overall, and the services part of the ICT sector tends to have more rapid productivity growth than the service sector as a whole. The large variation in performance across countries points, amongst other things, to varying specialisation within the ICT sector. Some countries are specialised in ICT production in which technological progress was not as fast as for semi-conductors or computers.

The *OECD* (2001A) study on Denmark, Finland and Germany – the only countries with sufficient data – gives some indications of this relationship. In Finland[14] and Germany the contribution of the ICT-producing sector increased dramatically in the second half compared to the first half of the 1990s. In contrast, the role of ICT-producing industries in Denmark declined over the same period.

Additionally, the importance of the ICT-producing sector for recent growth performance has been confirmed by several national studies. In Finland, mobile telephone producer Nokia accounted for 1.2 percentage points in the country's GDP growth of 4% in 1999, even though it produced only 4% of overall GDP (*Forsman*, 2000). Furthermore, labour productivity growth in the ICT services was substantially higher than in the total economy (*Flottum*, 1998). The Bank of Korea found that 40% of recent GDP growth in Korea came from the ICT sector, five times its 1999 share in GDP (*Yoo*, 2000). In the Netherlands, the ICT-producing sector accounted for about 17% of GDP growth over the 1995–98 period, four times its share in GDP (*CPB*, 2000). And a recent study in Canada attributes much of the Canada-US productivity gap in manufacturing to the performance of two sectors, machinery and electronic products, both of which are important producers of IT products (*GU and Ho*, 2000). The ICT-producing sector is thus an important driver of growth and productivity, although certain countries, such as Australia, have improved growth and productivity even though they are only very small producers of ICT-related goods and services.

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[14] See also *OECD* (2001a): "...Finland shows a substantial acceleration of MFP growth in both machinery and equipment and electrical and optical equipment in each subperiod. For Finland, the MFP calculations broadly confirm the importance of the ICT sector for overall MFP growth; about 20% of MFP growth over 1995–1999 is due to the ICT sector, which is substantially more than in previous periods."

Based on comprehensive research on the productivity impact of ICT on the sectoral level, *Stiroh* (2001) concludes that "... those industries that made the largest IT investment in the early 1990s show larger productivity gains in the late 1990s and production function estimates show a relatively large elasticity of IT capital, indicating that IT capital accumulation is important for business output and productivity." This result again hints that investment in ICT takes time to unfold its impact on output and productivity and underlines that productivity growth due to ICT is not confined to the ICT-producing sectors (see also *Bailey and Lawrence*, 2001, *Nordhaus*, 2001).

Stiroh (2001) produces further support by decomposing aggregate productivity growth into the contribution of individual industries and inter-industry reallocation effects and thus demonstrates that ICT-related differences are large and important for understanding the US productivity revival. ICT-producing and ICT-using industries account for almost all of the productivity revival that is attributable to the direct contributions from specific industries. Industries which were not essentially impacted by the ICT revolution made no contribution to the US productivity revival. Thus, the US productivity revival seems to be fundamentally linked to ICT.

Last but not least, the cyclical effect claimed by *Gordon* (2000) as the major factor behind the pickup in productivity should have happened at the beginning of the business cycle but not in the middle of it. The latter indicates that something structural in the economic process has changed. This productivity increase happens at exactly the same time that a significant increase in ICT spending was observable in the USA. Furthermore, if the productivity increase is a cyclical phenomenon it should be evenly distributed over industries and not be connected to ICT usage in the industry. According to *Stiroh* (2001), the opposite holds true: the most intensive users of ICT experienced the largest productivity gains, consistent with the idea that ICT has real economic benefits.

Overall – and as is demonstrated by a number of studies (*OECD*, 2000, Schreyer, 2000, *Scarpetta et al.*, 2000, *OECD*, 2000a, *Federal Reserve Board*, 2000) – it has to be emphasised that there is no single factor that by itself explains the divergence in growth performance between countries. Countries that improved performance in the 1990s have generally been able to draw more people into employment, have increased investment, and have boosted multi-factor productivity (MFP). ICT investment is playing a crucial and – likely – growing role in setting the foundation for future growth. Policies to stimulate ICT investment and use have to ensure that competition (and regulation) will further lower prices for ICT equipment and services, provide adequate skill upgrading which allows to draw more people into employment and support complementary organisational innovation at firm level.

5. Conclusions

The growing consensus that the positive growth and productivity performance in the USA is related to increased investment and diffusion of ICT goods and services has raised fears that the weaker economic performance of European Union member states is caused by a reluctance to adopt these new technologies.

The gap does not close quickly

Seen overall, the ICT spending gap between Europe and the USA widened in the 1990s, even though both regions expanded their expenditures: In 1992, European ICT expenditure per GDP (5.2%) was 2.3 percentage points below the US level. While the gap narrowed in the first half of the 1990s, it thereafter increased to 2.7 percentage points in the second half. Figures of ICT per GDP somewhat hide the more dynamic development in the USA: In 1992, European ICT expenditure still amounted to 90% of US expenditure, but by 1999 had dropped to about 75% of the US level. The gap is even larger for ICT investment in the business sector: In 1999, the US economy invested about 4.5% of GDP in information technologies. This is almost twice the European level of 2.4%.

Leading European countries are close to or have surpassed the USA in ICT expenditure

The situation in the European Union is marked by heterogeneous spending levels in the member states: While the UK and Sweden have already surpassed, and the Netherlands, Denmark and Ireland have drawn close to the US level in overall ICT expenditure, some of the larger countries drag the European average downwards.

Economic impact

Recent growth-accounting studies have demonstrated the increasing contribution of ICT to aggregate economic growth. In the USA, ICT investment explains 0.8 to 1 percentage point of output growth in the second half of the 1990s. Most studies found that the importance of ICT for economic growth more than doubled compared to the first half of the past decade. Estimates for European countries generally calculate a lower contribution of ICT to output growth. On average, about 0.4 to 0.5 percentage points of output growth in Europe are due to ICT. Compared to the USA, Europe seems to lose 0.3 to 0.5 percentage points of economic growth due to lacking investment in.

The acceleration of labour productivity is mainly due to capital deepening (0.1 to 0.33 percentage points) and multi-factor productivity growth (0.3 to 0.9 percentage points). Both categories are substantially influenced by IT usage and production. Nonetheless, the contribution of ICT to multi-factor productivity growth is strongly disputed. It is argued that the increase in labour productivity is a normal, cyclical acceleration as the economy expands. If this cyclical contribution is deducted, then the contribution to multi-factor productivity growth from the non-ICT-producing sector is negligible (or even negative). If productivity growth is confined to the ICT sector alone, but does not raise productivity in other sectors, it could be argued that there is no such thing as a "new" economy. Instead, the massive ICT investments outside the ICT-producing sector may be focused on unproductive activities like market share protection, duplication of existing operations, or on-the-job consumption and thus have a negative productivity impact.

Advocates of a more fundamental impact of ICT stress that productivity should have picked up at the beginning of the business cycle but not in the middle of it. The latter indicates that something structural in the economic process has changed. This productivity increase happens at exactly the same time as a significant increase in ICT spending was observable in USA. Furthermore, if the productivity increase is a cyclical phenomenon it should be evenly distributed across industries and not be connected to ICT usage in the industry.

Recent research rather emphasises the role of ICT investment for productivity growth: The evidence is growing that ICT does have a positive productivity impact in ICT-using industries. Studies from the USA and by OECD have demonstrated that both ICT producers and ICT users experienced significant productivity gains, consistent with the idea that ICT has real economic benefits. In contrast, industries which were not impacted by ICT initially made no contribution to the productivity revival.

The weak productivity performance in services – a heavy user of ICT – is related to well-known problems of measuring the output of services industries and the time it takes to implement ICT. To be successful, these technologies have to be coupled with organisational changes and upskilling of the labour force. Given the complementary investments necessary, it is not surprising that most of the evidence of the positive productivity impact of ICT usage was obtained only recently. The size of the ICT capital stock was too small and the time to implement the technology too short, with the consequence that the impact was not visible until the second half of the 1990s.

In general – and also demonstrated by a number of studies – it has to be emphasised that there is no single factor to explain the divergence in growth performance between countries. Countries that have improved performance in the 1990s have generally been able to draw more people into employment, have increased investment, and have improved multi-factor productivity (MFP). ICT investment is playing a crucial and probably growing role in setting the foundation for future growth. Policies to stimulate ICT investment and use have to ensure that competition (and regulation) will further lower prices for ICT equipment and services, and provide adequate skill upgrading which makes it possible to draw more people into employment and support complementary organisational innovation at firm level.

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