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The *New Economy* in Europe, 1992-2001

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Abstract

Despite the fast catching-up in ICT diffusion experienced by most EU countries in the last few years, information technologies have so far delivered little productivity gains in Europe. In the second half of the past decade, growth contributions from ICT capital rose in six EU countries only (the UK, Denmark, Finland, Sweden, Ireland and Greece). Quite unlike the United States, this has not generally been associated to higher labour or total factor productivity growth rates, the only exceptions being Ireland and Greece. Particularly worrisome, the large countries in continental Europe (Germany, France, Italy and Spain) showed stagnating or mildly declining growth contributions from ICT capital, together with definite declines in TFP growth compared to the first half of the 1990s. It looks like that the celebrated 'Solow paradox' on the lack of correlation between ICT investment and productivity growth has fled the US to migrate to Europe.

Keywords: economic growth, productivity growth, Europe, information and communication technologies, total factor productivity

JEL classification: O3, O4, O5

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1 Introduction

Productivity trends across the two shores of the Atlantic Ocean could hardly be more diverse than today. In the United States, as a result of the current slowdown, the growth rate of labour productivity fell from 3.3 per cent in 2000 to 1.9 per cent in 2001. Yet, the 2001 growth rate is only half a percentage point smaller than in 1995-2000, the brightest period for the US economy in the last thirty years. In contrast, the near-stagnation of labour productivity experienced by the EU in 2001 (+0.4 per cent) is simply another episode of a declining growth trend, which dates back—quite independently of cyclical fluctuations—at least to the early 1990s.

Many commentators relate the extraordinary growth performance of the US economy to information technology (ICT).[1] About two-thirds of the US growth resurgence of the second part of the 1990s has been attributed to the enhanced capital accumulation and the acceleration in the pace of technical change enabled by the production and diffusion of information technology. According to the October 2001 survey of the US Department of Commerce, two Americans out of three use a computer at home, in school or at work, and the 80 per cent of those who use a computer are also connected to the Internet. No wonder that information technology is thought of doing magic to productivity growth in the United States.

Bearing these figures in mind, a first-hand presumption is that Europe's disappointing growth performance may be caused by the delayed diffusion of ICT in the EU economies. If the US is a *new economy*, i.e., its long-run labour productivity growth rate is now higher than in the past, and Europe is not, this may be because Europe 'lags behind' in the production and adoption of information technology.

The purpose of this paper is to evaluate this argument. This is done in two steps.

In the first part of the paper, the extent of ICT diffusion in Europe is documented. Available data show that, in the 1990s, ICT spending and investment were much smaller in the EU than in the US. It is also shown that within Europe, ICT diffusion was sharply diversified, with Nordic countries, the Netherlands and the UK being the front-runners and the rest of the EU making slow progress in ICT adoption.

Recent data are suggestive of a substantial acceleration in the introduction of information technologies in European countries, particularly in 2000 and 2001. While the EU-US gap has not been fully bridged yet, evidence is accumulating that Europe's catching-up is being much faster than most observers (including myself) would have anticipated some time ago. It remains true, however, that about one-third of the Union has not seen the ICT diffusion gap with respect to both the US and the rest of Europe narrowing down in the last few years. The typical country in the group of the 'slow-adopters' (Ireland, Italy, Spain, Greece and Portugal) spent 6 per cent and invested 2.5

1 The consensus on the crucial role played by information technologies in the United States is general. Oliner and Sichel (2000) and Jorgenson and Stiroh (2000) found evidence that the growth contribution of information technologies was small in 1974-95, and markedly higher in 1996-2000. Controversies arose as to the permanent/temporary nature of the 1990s productivity growth gains. Gordon (2000, 2001) stressed their narrow scope to the computer-producing sector, casting fundamental doubts as to the mere existence of a *new economy*. Nordhaus (2001) and Stiroh (2001), instead, found evidence of productivity spillovers outside durable manufacturing into traditionally low-productivity growth sectors, such as trade and finance.

per cent of its GDP in ICT goods in 2001. A typical country in the rest of the EU would instead spend and invest about 50 per cent more, i.e., respectively 9 per cent and 3.7 per cent of its GDP in ICT goods, not too far apart from current US levels.

Overall, as of 2001, the EU as a whole no longer appears to seriously lag behind the United States in terms of information technology adoption. ICT diffusion is just one of two ingredients for growth, though. As first pointed out by Solow (1987), sinking money in computers is not enough to propel productivity growth, unless this occurs in parallel with wide-ranging organizational changes in the modes of production. To investigate this other potential source of the EU-US productivity gap in more depth, numerical estimates of the growth contributions of ICT capital are presented in the second part of the paper.

While the actual size of the growth effects of ICT in Europe is still surrounded by large measurement error, the overall picture from the available aggregate data is not. In the second half of the past decade, the growth contributions from ICT capital rose in six EU countries only (the UK, Denmark, Finland, Sweden, Ireland and Greece). Quite unlike the United States, this has not generally been associated to higher labour or total factor productivity growth rates, the only exceptions being Ireland and Greece. Particularly worrisome, the large countries in continental Europe (Germany, France, Italy and Spain) showed stagnating or mildly declining growth contributions from ICT capital, together with definite declines in TFP growth compared to the first half of the 1990s.

Hence, despite the catching-up in ICT diffusion experienced by most EU countries in recent years, information technologies have so far delivered little, if any, productivity gains in Europe. It looks like that the celebrated ‘Solow paradox’ on the lack of correlation between ICT investment and productivity growth has fled the US to migrate to Europe.

The structure of the paper is as follows. Section 2 presents a short recollection of measurement issues and definitions of the main ICT-related items. Section 3 is the description of the evidence on the diffusion of ICT in the EU during the Internet decade (1992-2001). In section 4, the evidence from the growth accounting decomposition of labour productivity growth into its capital deepening and TFP components is presented for the EU countries. In Section 5, the results from different studies are contrasted. Section 6 concludes.

2 Measurement and other data issues

The so-called ‘information economy’ is associated to the increased diffusion of information and communication technologies. As information technologies spread across the economy, households, firms and the various tiers of government are supposed to allocate larger fractions of their total resources to ICT goods and services. This is expected to drive up the GDP share of ICT spending. Moreover, another possibly important aspect of the ICT revolution is the extent to which ICT spending is broken down into investment and consumption of services. In order for large growth-enhancing effects of information technology to materialize, ICT diffusion should be associated to higher GDP and total investment shares of ICT investment.

2.1 Measurement issues

Providing cross-country comparable series of ICT spending and investment is not an easy task. Although substantial progress is under way (see the work in preparation by van Ark *et al.* (2002)), there are still significant differences in the availability and the level of detail at which statistical offices in OECD countries publish data on gross fixed capital formation by type of investment good, including ICT goods.

In the United States, after a decade-long process of data revision,[2] the Bureau of Economic Analysis at the Department of Commerce regularly releases nominal investment spending, 'chained' real investment data and hedonic (i.e., quality-adjusted) price indices for hardware, software and communications equipment.

The picture is quite different for Europe. The few statistical offices that provide separate information about ICT capital goods usually do it for the whole economy rather than for the business sector. Moreover, as reported in Scarpetta *et al.* (2000: 89 and 92), only a handful of countries in Europe employ quality-adjusted price indices and chained methods in computing their real GDP. Hedonic prices for computers are computed in Denmark, France and Sweden. (Denmark converts the US price index into Danish Crowns right away.) Real GDP growth is computed through yearly-adjusted ('chained') weights in France, Greece, the Netherlands and Portugal only. In the other countries in the EU, real GDP is still computed employing Laspeyres initial-weight methods.

This heterogeneity of statistical methods may lead to significant differences in measured price changes for these products. Concern has been raised about the international comparability of volume growth rates of GDP in the presence of heterogeneous accounting practices. Schreyer (2002) has usefully discussed the possible consequences for measures of economic growth of replacing one set of price indices by another one in the framework of national accounts. His main conclusion is that the issue of ICT deflators cannot be dealt with in isolation and several other factors have to be taken into account, in particular whether ICT products are final or intermediate products, whether they are imported or domestically produced, and whether national accounts are set up with fixed or chain weighted index numbers. Overall, somehow reassuringly, Schreyer's results point to modest effects of mismeasurement at the level of the aggregate GDP.[3]

2.2 Data source and definitions

The main primary source of cross-country ICT spending data relied on here is not an official one, such as national statistical offices, the OECD or the World Bank. Rather, it is a private consortium of 48 ICT industries association named WITSA (World Information Technology and Services Alliance). WITSA's *Digital Planet* reports,

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2 See Moulton (2000) for a concise rendition of the main methodological changes entailed by this revision.

3 Distortions may be more significant instead when it comes to component measures such as volume growth of investment, or of output in particular industry. For a recent survey of these and other measurement issues, see van Ark (2002).

published every other year since 1998, have kept track of ICT developments in some 50 countries in the world—about 98 per cent of the total world ICT market—since 1992.

In its studies, WITSA relies on the work of International Data Corporation (IDC), a private consulting company specialized in high-tech industries research. IDC employs consistent definitions for measuring ICT spending through firm-level surveys, country by country. This is a clear advantage compared to individual country studies, which may use government statistics inconsistently defined across countries. Unfortunately, though, IDC does not publicly release important pieces of information on the size and the structure of its survey, whose overall degree of comprehensiveness remains therefore hard to gauge to an outside observer. Moreover, IDC definitions do not exactly match national accounting definitions (see below). In spite of these shortcomings, the OECD (1999, 2001) did take advantage of IDC data to monitor the evolution of the ICT market.

The definitions of ICT items relevant here are as follows.

ICT spending: WITSA spending data concern sales of hardware, software and related ICT services, both external and internal to the firm, plus telecommunications in 1992-2001. They reflect the revenues paid to primary vendors and distribution channels (hence outside the purchasing entity) for office machines, data processing systems, software and services by the final customer. Final customers include corporations, households, schools and government agencies. Spending on the part of unincorporated enterprises is left out.

Hardware: The WITSA item for ICT hardware spending includes server systems, workstations, personal computers, printers, data communication equipment and add-ons to each of these items. It excludes office equipment, such as typewriters, calculators and copiers.

Software: The *Digital Planet* item for ICT software spending includes the purchases of system and application software products, i.e., 'pre-packaged' and 'custom' software in the BEA terminology. It does not include internal expenses related to the customization of computer programmes, i.e., 'own-account' software in the BEA terminology. These other software expenses are jammed together in 'ICT internal spending', i.e. an overhead item mixing up capital depreciation and other firm-level spending in ICT not related to a specific vendor.

Telecommunications: The 'telecommunications spending' reported in *Digital Planet* 2002 includes expenditures on public network equipment, private network equipment and telecommunications services.

ICT investment: To calculate business sector investment in hardware, software and communications equipment for all of the EU countries, household and government spending are to be subtracted out of total spending. Unfortunately, the distinction between private and public spending, as well as between the household and the business sector, cannot be recovered within the broad WITSA spending item. In the next section, as in Daveri (2000, 2001a), a fraction of total spending is imputed to business sector investment, by computing the 1992-2001 average ratio between the actual figure for business sector investment provided by the BEA and the corresponding WITSA spending item for the United States. BEA hardware investment turns out to be about 59 per cent of total hardware spending. BEA communications equipment is about 33 per cent of total telecommunications spending. BEA software investment is about 205 per cent of the WITSA software item (which does not include own-account software). These coefficients are then multiplied by the corresponding WITSA spending items for EU countries to derive nominal ICT investment spending data in 1992-2001.

ICT price indices: As mentioned at the beginning of this section, hedonic price deflators for information technology goods simply do not exist for most EU countries. They are instead available for the US. Scholars working in this field somehow swept these issues under the rug by super-imposing a close similarity between the price dynamics of ICT equipment in the US and elsewhere. Wyckoff (1995) initiated this practice. Schreyer (2000), Daveri (2000, 2001a), Colecchia and Schreyer (2002) and others followed suit. This can be done either constructing a 'harmonized' price level (as in Schreyer (2000) and Colecchia and Schreyer (2002)) or directly converting the US price level in the relevant EU currency (as in Daveri (2000, 2001a)). In both cases, a weak (growth-rate) version of the purchasing power parity hypothesis is assumed to hold. This may not be a bad approximation, given the high tradability of ICT goods. Real investment data are then computed dividing nominal investments by the price indices obtained as above.

3 The diffusion of ICT in Europe

3.1 Europe versus the US

Europe is often reckoned to lag behind the United States in terms of ICT adoption. Available data on ICT spending and investment—the most readily available measures of ICT diffusion from WITSA (2002)—show that, as of 2001, this is no longer the case, at least for Europe as a whole.

WITSA data are available starting FROM 1992, one year after the Internet protocol was signed. At that time, the EU as a whole is recorded to have spent about 5.3 per cent of its GDP in ICT goods and services, i.e., 1.9 percentage points less than the US. As shown in Figure 1, ICT spending rose by about ONE percentage point of GDP in each of the two areas in 1992-98, thereby leaving the spending gap roughly unchanged. Since then, the EU-US spending gap has been closed at a fast pace. In 2001, the GDP share of ICT spending has even become slightly higher in the European Union than in the US.

Overall, Europeans increased the fraction of their income devoted to information technologies by about three percentage points in 1992-2001. The rise of ICT spending in the US was clearly more modest, less than one percentage point in nine years. As to Europe, the 1.5 points rise in 2000-2001 marks a clear watershed compared to both 1992-96 (when the ICT spending share went up by a mere 0.3 p.p.) and 1997-99 (when the increase has risen already to about 0.4 p.p. per year).

A not too dissimilar picture is dashed for ICT investment in Figure 2, except that the EU-US gap in ICT investment persisted for much longer than the ICT spending gap. Europe used to invest about 1.8 per cent of its GDP in ICT in 1992, about 0.6 percentage points less than the US. Then ICT investment rose in both areas, and the gap smoothly increased as well to a full percentage point. At the 2000 peak, ICT investment totalled some 3 per cent of the EU GDP and 4 per cent of the US GDP. During the 2001 slowdown, ICT investment slightly further increased to 3.3 per cent of GDP in the EU and instead declined to 3.6 per cent of the US GDP. Hence, by 2001, the ICT investment gap between the EU and the US has been abruptly reduced as well.

Figure 1
IT spending/GDP, European Union versus the United States

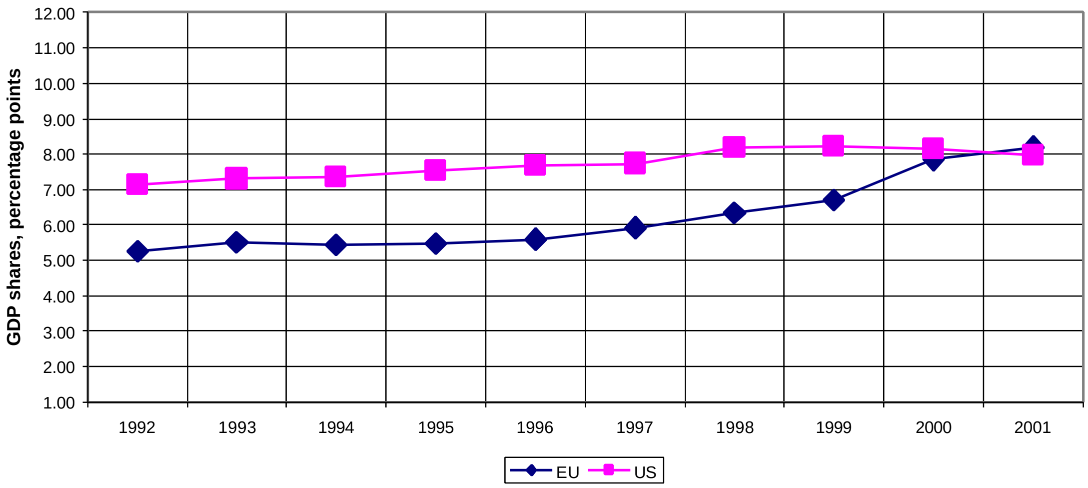
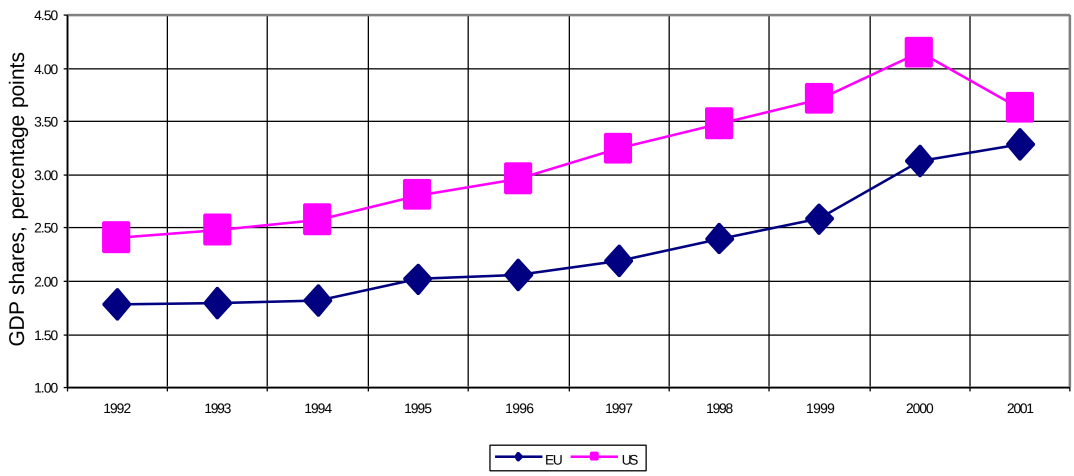


Figure 2
IT investment/GDP, European Union versus United States



3.2 Within Europe

Has the process of catching-up of the European Union as a whole with respect to the United States occurred on a country-by-country basis as well? Or rather is the convergence of the EU to US levels of spending and investment the result of a widening of cross-country differences?

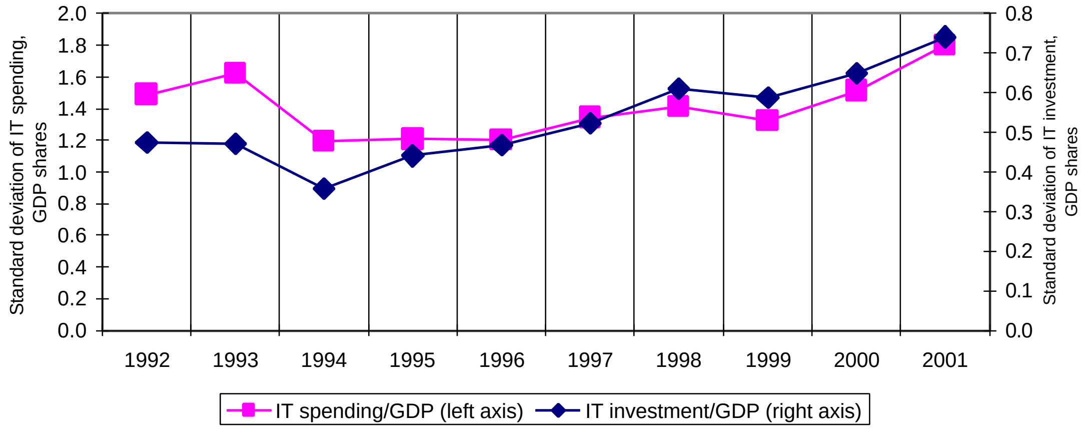
In principle, both may be consistent with aggregate catching-up. In practice, convergence within the EU has not occurred in 1992-2001, in particular during the last few years when the process of catching-up of the Union as a whole has accelerated.

Table 1 presents evidence on the differences in ICT spending between fourteen EU countries (excluding Luxembourg, but including benchmark figures for the EU as a whole and the US) in 1992-2001. Countries are entered in Table 1 in descending order of their GDP shares of ICT spending in 1992. In the left-hand panel of Table 1, point-wise data for 1992, 1998 and 2001, as well as the nine-year averages, of the GDP shares of ICT spending are provided. In the right-hand panel of Table 1, period changes of the same shares are given over 1992-2001, 1992-98, 1998-2001 and 2000-01.

Table 1
ICT spending as a share of GDP

	GDP shares, % points				Changes of GDP shares, % points			
	1992	1998	2001	1992-2001	1992-2001	1992-98	1998-2001	2000-01
EU	5.26	5.93	8.20	6.23	+2.94	+1.07	+1.87	+0.36
SWE	7.34	9.09	11.55	8.63	+4.21	+1.75	+2.46	+1.16
UK	7.07	7.87	9.79	7.97	+2.72	+0.80	+1.92	+0.65
NET	6.39	7.76	9.55	7.39	+3.16	+1.38	+1.78	+0.15
DEN	6.13	7.38	9.52	7.19	+3.39	+1.26	+2.13	+0.38
FRA	5.71	6.86	9.18	6.75	+3.47	+1.15	+2.32	+0.52
BEL	5.37	6.60	8.26	6.36	+2.89	+1.23	+1.66	+0.29
GER	5.26	6.15	8.23	6.07	+2.97	+0.90	+2.07	+0.37
AUT	4.87	5.66	7.46	5.52	+2.59	+0.79	+1.80	+0.24
FIN	4.63	6.42	8.01	6.16	+3.38	+1.79	+1.59	+0.25
IRE	5.38	5.88	6.21	5.80	+0.83	+0.51	+0.32	-0.45
SPA	3.70	4.11	5.23	4.21	+1.54	+0.42	+1.12	+0.09
ITA	3.65	4.50	5.86	4.49	+2.21	+0.85	+1.36	+0.14
POR	2.79	5.00	6.74	4.91	+3.96	+2.21	+1.74	-0.31
GRE	2.46	5.05	6.30	4.34	+3.84	+2.59	+1.25	+0.10
USA	7.14	7.73	7.96	7.73	+0.82	+1.05	-0.23	-0.20

Figure 3
Cross-country variability of IT spending and investment,
European Union countries



The relevant asymmetries within Europe both in the extent and the variation of ICT spending are documented in Table 1. The fraction of income destined to information technologies in Spain in 2001 is 40 per cent of the amount of resources spent in ICT in Sweden and three percentage points less than the EU average. ICT spending above the EU average, associated with its sizeable increase, features consistently in Denmark, the Netherlands and the UK. Ireland, Italy, Portugal and Greece form instead a group of low ICT spenders with Spain, while Germany, France, Belgium and Austria are somewhere in between these two extremes. In general, the presence of significant inter-country differences is hardly surprising,[4] but it cannot certainly go unnoticed.

The thrust of Table 1 can be concisely summarized in Figure 3, where the cross-sectional standard deviations of ICT spending and investment shares are plotted. It turns out that neither has declined over time. In the first half of the 1990s, the cross-country variability of both ICT spending and investment declined fast. Yet this was mainly the result of the rapid increase undergone by spending and investment shares in Greece, Portugal and Finland. In the wake of the initial fall, variability started increasing eventually, early on (1995) for spending and somewhat later (1998) for investment. As a result, neither standard deviation is lower in 2001 than in 1992.

To sum up, individual country evidence suggests that the acceleration of ICT spending and investment in the EU as a whole in 1998-2001 has gone hand in hand with higher inequality in ICT diffusion within Europe.

In fact, as to ICT diffusion, EU countries can be clustered in two groups. The typical country in the group of 'slow adopters' (Ireland, Italy, Spain, Greece and Portugal) spent 6 per cent and invested 2.5 per cent of its GDP in ICT goods in 2001.

4 IT diffusion varies substantially across states in the US as well. While spending data are still unavailable, the US Department of Commerce (2002: 10) reports that the fraction of Internet users is around 42 per cent of total population in Mississippi and 69 per cent of total population in Alaska as of September 2001.

Slow adopters represent about one fourth of the EU GDP and one-third of the EU population. A typical country in the rest of the EU would instead spend and invest about 50 per cent more, i.e., respectively 9 per cent and 3.7 per cent of its GDP in ICT goods (in both cases, arithmetic means are considered).

3.3 A little discussion

Before moving on, it is worth asking whether and how the extent of the within-EU asymmetries emphasized so far is related to the measurement issues discussed in the previous section. In fact, WITSA data may bias cross-country rankings in three ways. The direction of the bias is in principle unclear, however.

The actual ICT spending and investment gap between slow and fast adopters may be over-estimated for two reasons. As mentioned above, ICT spending of unincorporated enterprises is left out of WITSA nominal spending data. Moreover, nominal investment shares are computed assuming that the non-business investment share of ICT spending is the same in all countries as in the US. For both reasons, the available ICT investment data may be biased downwards for those European countries, such as Italy, Greece, Spain and Portugal, where small-sized enterprises disproportionately contribute to output and employment. The actual ICT investment gap between the two groups may thus be smaller than the measured gap.

The GDP shares data discussed so far are subject to another source of bias, though. Table 1 and Figures 1 through 3 focus on nominal GDP shares. As discussed in Whelan (2000: 11), this makes sense, for real investment shares are not easy to interpret when real data are obtained from chained rather than fixed-weight data (in particular, the GDP components no longer add to real GDP—not a minor nuisance). Yet, nominal shares also contain a price component, which affects both time and space variation of the shares. Therefore, if the relative price of tradable goods is higher in poor than in rich countries (the so-called 'Balassa-Samuelson' effect), then the relative price of ICT goods is plausibly higher in the relatively poorer slow adopters than in the rest of Europe. By this channel, at a given point in time, nominal shares would tend to underestimate the actual extent of the investment gap between slow and fast adopters. Hence this other effect goes in the opposite direction of the first two effects.

In conclusion, WITSA investment figures may be biased upwards or downwards, but the three effects potentially offset each other. Evaluating the relative strength of the two biases without directly observing the prices of the ICT goods remains hard, however.

4 ICT and growth in Europe

In the previous section, the progress of EU countries with ICT diffusion has been documented. Here a step forward is taken and the attention is shifted onto the relation between the diffusion of information technologies and growth. The main point made in this section is that the partial spending and investment catching-up previously documented is largely unrelated to productivity growth developments.

In section 4.1 the building blocks of the growth accounting methodology are described. In section 4.2, the growth accounting results on the relation between ICT and productivity growth in the EU are presented.

4.1 The growth accounting methodology

Since Solow (1957), growth accounting exercises have been employed to decompose the growth rates of total or per-capita output into their capital, labour, technical change components. Initially, starting with Solow's paper, most authors found that growth was predominantly explained by technical change, i.e., the fraction of GDP growth unexplained by factor accumulation. Jorgenson and Griliches (1967) then showed that allowing for changes in capital and labour quality may absorb the bulk of the (unexplained) TFP growth within the (explained) factor accumulation component. The recent papers on the role of information technology in the US economy by Oliner and Sichel (2000) and Jorgenson and Stiroh (2000) belong to this framework of analysis.

The growth accounting exercise whose results are reported in subsection 4.2 and 4.3 consists in decomposing GDP growth into its labour (hours worked), capital and total factor productivity components. In turn, the contribution of capital accumulation to growth is further attributed to three components (communications equipment, hardware and software) related to information technology, and a residual item, i.e., 'other capital', which lumps together the various categories of non-ICT productive capital. The decomposition of growth contributions by input, under the standard assumptions of constant returns to scale and perfect competition, is the following:

$$\dot{q} = (1 - s'_K)\dot{l} + s_{COM}\dot{k}_{COM} + s_{HW}\dot{k}_{HW} + s_{SW}\dot{k}_{SW} + s_{OTK}\dot{k}_{OTK} + \dot{a} \qquad (1)$$

where s_C is the capital income share of capital good C ($C = COM, HW, SW, OTK$) averaged over time t and $t\text{-}1$; s'_K is equal to s_K, the capital share computed from national accounts, with the standard correction for self-employment[5] and augmented of s_{SW}, the software share;[6] dotted q, l, k_{COM} , k_{HW}, k_{SW}, k_{OTK}, a are, respectively, the growth rates of output, total hours worked, capital in communication equipment, quality-adjusted hardware, software, and other (non-ICT) capital, and the well known 'Solow residual', a residual item supposed to measure disembodied technical change or total factor productivity growth (TFP).[7]

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5 'Correcting for self-employment' implies calculating capital income as the difference between the value added net of indirect taxes and subsidies, on the one hand, and wages and salaries of the employees multiplied by the ratio between total employment and the employees, on the other. Hence this correction assumes that the average labour income of a self-employed is the same as the average labour income of an employee.

6 As mentioned above, software was not accounted as an investment good until recently. This implies that the capital stocks reported in the OECD *Economic Outlook* do not include software.

7 GDP, employment, aggregate capital and the capital income shares sK for the business sector are taken from the OECD *Economic Outlook*. The average number of hours worked is from Scarpetta *et al.* (2000: 83-Table A.13).

The computed value of the TFP component is affected in its extent by a host of implementation assumptions. In addition to constant returns and perfect competition, equation (1) as implemented here does not embody any correction for changes in the composition of the labour force, unobserved changes in utilization of factors other than labour, reallocation of inputs across uses and adjustment costs to changing inputs. [8]

The value added share of each capital good k (s_k) is computed, as in Hall and Jorgenson (1967), as follows:

$$s_k = (r + d_k - \dot{p}_k) \frac{P_k K}{PY} \tag{2}$$

i.e., the product of the gross rate of return on capital (the term in parentheses) and the capital-output ratio in nominal terms. In turn, r is the nominal market rate of return on investment, δ_k is the depreciation rate of good k, dotted p_k is the capital gain or loss on the possess of capital good k, and P_k equals the purchasing price of a new capital good (p_k being its log). The expression in parentheses times P_k is the user cost of capital, i.e., the rental price charged if capital good k were to be rented for one period. [9]

Finally, equation (1) can be slightly rewritten so as to emphasize the decomposition of productivity growth per man hour into the capital deepening and TFP components suggested by the production function approach to productivity issues:

$$\dot{q} - \dot{l} = s_{COM}\left(\dot{k}_{COM} - \dot{l}\right) + s_{HW}\left(\dot{k}_{HW} - \dot{l}\right) + s_{SW}\left(\dot{k}_{SW} - \dot{l}\right) + s_{OTK}\left(\dot{k}_{OTK} - \dot{l}\right) + \dot{a} \tag{3}$$

The ‘capital deepening’ part is represented by the first four terms on the right-hand side of (3). Each of the four terms is the contribution to growth (in per-worker terms) of a capital good. The contribution of ICT capital to labour productivity growth discussed about in the next section is the sum of the first three terms on the right-hand side.

Altogether, equation (1)-(3) usefully clarify that the growth contribution from ICT capital goods may be high for three reasons: (i) fast capital accumulation, (ii) a high gross rate of return, (iii) a high capital-output ratio. As discussed below, these three elements do not always move upwards and downwards in parallel.

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8 Basu, Fernald and Shapiro (2001) find that these other effects and imperfections were overall unimportant for the US in the late 1990s. No such study has been undertaken for EU countries so far, though.

9 Further details on the actual implementation of the growth accounting methodology are given in the Appendix.

4.2 ICT and productivity growth in EU countries

In their 2000 paper, Oliner and Sichel conclude that the US growth resurgence in the 1990s is largely an information technology story. They calculated that about two-thirds of the rise in US labour productivity in 1996-99 is due to the increased use and production of information technology. These two-thirds can be partly attributed to capital deepening and partly to higher TFP growth, mostly in the sector producing computers. Similar results are in Jorgenson and Stiroh (2000). Here it is asked whether the growth gap suffered by EU countries with respect to the US in the 1990s and the early 2000s can be related to the gap in the accumulation of ICT capital.[10]

As anticipated in the introductory section of this paper, the EU as a whole experienced a growth slowdown in the second half of the 1990s, quite unlike the United States. The 2001 slowdown brought productivity growth down to zero or even negative figures in most EU countries, including Germany, France, Italy, Spain, the Netherlands, Sweden, Finland Portugal, Belgium and Austria.[11]

To follow up on previous discussion, Table 2 reports the period changes in the growth rates of labour productivity before and after some time-threshold for the groups of the slow and fast ICT adopters. The evidence shows no appreciable difference in the growth performances of the two groups of countries.

If, in line with the US literature, 1995 is picked as the time-threshold between the early stages and a more mature phase of the Internet-based economy, the (arithmetic) average changes in labour productivity growth are in fact very close to zero for both groups. Within the slow adopters group, Ireland and Greece saw their growth performances going up sensibly over time. The reverse happened instead to Italy and Spain. As a result, the group average change in productivity growth is moderately positive (+0.2 per cent), but with a high within-group standard deviation (2.1 per cent). The fast adopters experienced even a slightly negative change in productivity growth in 1996-2001 compared to 1990-95 (-0.3 per cent), with little variability above and below that figure.

Very similar conclusions are reached when 1998 is taken as a benchmark and the changes in productivity growth in 1999-2000 and 1992-98 are looked at. In other words, even when the 2001 slowdown is left out and an EU-specific turning point for the surge in ICT spending (such as 1998) is picked, no evidence is found of an acceleration in the rate of productivity growth in either group.

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10 In a recent paper, van Ark, Inklaar and McGuckin (2002) interestingly extend aggregate results by taking a sector perspective. In their paper, the bulk of the EU-US growth gap of the 1990s is shown to be due to a handful of sectors, i.e., retail and wholesale trade and the securities sectors. While these results are important in themselves, whether they are to be taken as further proof that information technologies played an important role in determining the EU-US growth gap remains to be seen.

11 This part of this section partly draws on my contribution to CEPS (2002: ch. I).

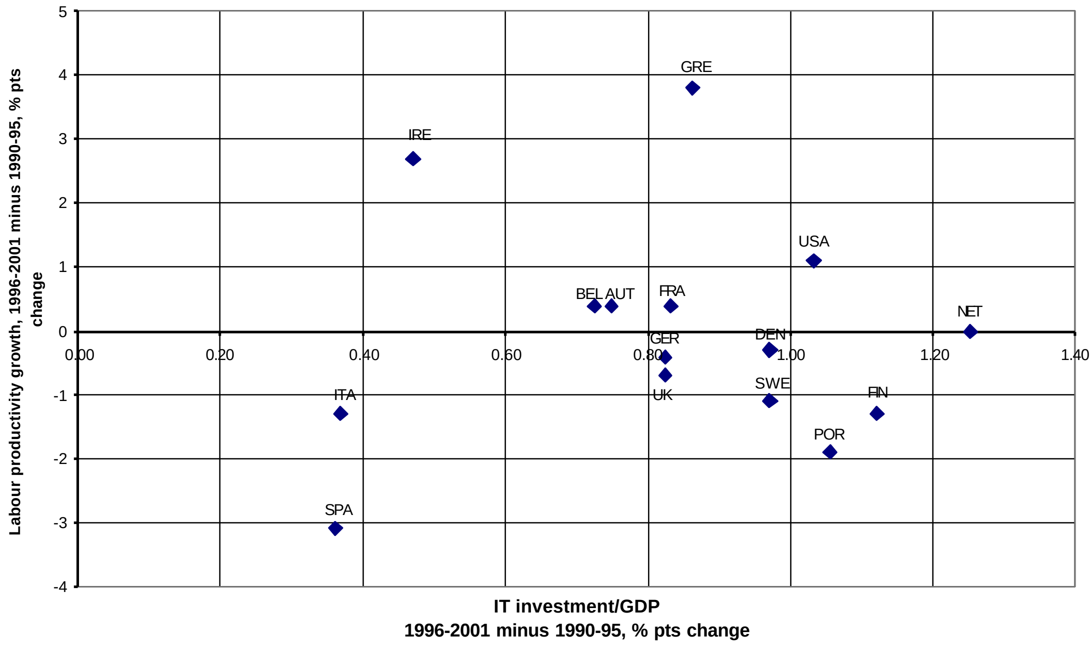
Table 2
Change in growth rates of labour productivity (per cent points)

	(1)	(2)
	Δ growth rate of GDP per employed person	
	1996-2001 vs. 1990-95	1999-2000 vs. 1992-98
USA	+1.1	+0.8
EU 15	-0.8	-0.7
Fast ICT-adopters	-0.29 (st.dev.=0.32)	-0.27 (st.dev.=0.65)
SWE	-1.1	-0.8
UK	-0.7	-0.4
NET	+0.0	-0.1
DEN	-0.3	-0.5
FRA	+0.4	-0.2
BEL	+0.4	-0.3
GER (*)	-0.4	-0.4
AUT	+0.4	+0.3
FIN	-1.3	+0.0
Slow ICT-adopters	+0.04 (st.dev.=2.13)	+0.16 (st.dev.=3.03)
IRE	+2.7	+1.1
SPA	-3.1	-2.5
ITA	-1.3	-1.4
POR	-1.9	+0.7
GRE	+3.8	+2.9

Notes: (*) 1990-95 data for Germany, in fact, refer to 1992-95.
The group averages for Fast and Slow ICT-adopters are arithmetic. The EU 15 average is weighted by each country's population in each year.

Source: CEPS (2002).

Figure 4
The IT 'productivity paradox' in Europe



This same conclusion is reached by looking at the lack of correlation implicit in Figure 4, where the period changes of the ICT investment share and the growth rate of labour productivity growth in 1996-2001 with respect to 1990-95 (1992-95 for Germany) are contrasted. An interpolating line fitted through the data points would give an R2 equal to zero. This is further evidence of the absence of correlation between ICT investment effort and productivity growth.

To recap, the aggregate catching-up in ICT spending for the EU had no counterpart in terms of productivity growth so far. Within Europe, ICT efforts are outright unrelated to parallel performances in terms of growth rates.

This may be the case for two possibly complementary reasons. ICT investment might be simply unproductive on impact and hence generate no additional output upfront, when the investment cost is sunk. This hypothesis has been studied extensively and contrasted with stock markets data to provide a unified rationale of the 1970s productivity slowdown and the 1990s growth resurgence (see, for example, Greenwood and Jovanovic 1999). Due to learning effects, the introduction of information technologies results in extremely high costs of adjustment, with an adverse effect on the stock market and productivity growth for some time until the new invention has been absorbed. This is a potentially useful hypothesis for Europe as well. It is unfortunately still hard to evaluate, for the upsurge in ICT spending in the EU is too recent.

The second possibility is that ICT investment and spending have had positive growth effects already, but other factors have more than offset their beneficial effects.

This conjecture can be evaluated in Table 3, where the changes in the growth contributions from ICT capital (per hour worked) and TFP growth between the first and the second half of the 1990s are reported. The growth contributions in Table 3 are simply the sum of the growth contributions of each of the three ICT capital goods in (3) added together using the respective user costs as weight. TFP growth is, as usual, the residual obtained after subtracting the growth contributions of ICT and non-ICT capital from the growth rate of labour productivity. Looking at both the growth contributions from ICT as well as TFP growth is worthwhile, for information technologies may positively affect the growth rate of labour productivity through both channels (capital deepening and TFP).

While the actual size of the growth effects of ICT in Europe is still surrounded by large measurement error, the overall picture from the available aggregate data is not.

The marginal growth contribution of ICT capital (the ‘capital deepening’ effect) to the acceleration of labour productivity growth is low on average (about a tenth of a percentage point). It is slightly higher for the fast adopters than for the slow adopters (0.13 percentage points against 0.09). It is nevertheless much smaller than 0.5 percentage points, i.e., the ICT growth contribution computed by Oliner and Sichel (2000: Table 2) for the US.

Table 3 also shows that there are exceptions to this pattern, however. The most notable one is the UK, where the additional ICT growth contribution amounts to about two-thirds of a percentage point. This has not materialized in higher labour productivity growth mainly for the parallel decline in TFP growth experienced in the United Kingdom between the first and the second part of the 1990s.

Sweden and Finland also earned a positive additional growth contribution of about 0.3 percentage points from ICT capital. This was more than offset, however, by the decline in TFP growth in Sweden and by the (not reported) decline in the contribution of non-ICT capital in Finland.

In Ireland and, to a lesser extent, Greece, instead, the positive contributions from ICT capital have been supplemented by increases in TFP growth. In spite of their limited ICT investment shares, both countries benefited from comparatively high rates of return on investment (about 4.5 per cent in real terms in the second part of the 1990s). In Ireland, this was clearly related to the presence of ICT multinational corporations.

The other large EU countries experienced, one way or another, negative additional growth contributions from capital deepening and TFP growth. This effect was moderate in Germany, France, Denmark, Belgium and the Netherlands. It was instead more dramatic in Italy and Spain, where ICT capital deepening did not take off and average TFP growth actually slowed down considerably by 1.4 per cent and 2.5 per cent in 1996-99.

Table 3
Change in growth contributions and in TFP growth (per cent points)

	(1)	(2)
	Δ growth contribution of ICT capital per man hour	Δ TFP growth
	1996-99 versus 1991-95	1996-99 versus 1991-95
Fast ICT-adopters	+0.13 (st.dev.=0.27)	-0.17 (st.dev.=1.39)
SWE	0.33	-0.41
UK	0.68	-1.19
NET	-0.08	-0.94
DEN	0.14	-2.37
FRA	-0.02	0.24
BEL	-0.07	-0.43
GER (*)	-0.14	-0.06
AUT	0.04	2.46
FIN	0.32	1.13
Slow ICT-adopters	+0.09 (st.dev.=0.20)	+0.14 (st.dev.=1.55)
IRE	0.35	0.59
SPA	-0.18	-0.90
ITA	-0.01	-1.96
POR	0.07	1.11
GRE	0.21	1.86

Notes: (*) 1990-95 data for Germany, in fact, refer to 1992-95.
The group averages for fast and slow ICT-adopters are arithmetic. The EU 15 average is weighted by each country's population in each year.

Source: CEPS (2002).

As apparent in equation (1)-(3), the numerical values of the growth contributions are the combined outcome of three elements, i.e., rates of accumulation, rates of return on investment and capital-output ratios. Further decomposing the growth contributions from ICT capital into these three components helps achieve a fuller understanding of the modes of introduction of information technologies in Europe.

The main result from this exercise (not reported here for brevity) is that differences in accumulation rates have generally swamped differences in rates of return and capital-output ratios. There is usually a close correlation between the rates of accumulation of ICT capital and the computed contribution from this type of capital. Whenever information technologies made a small contribution to growth, this was seemingly due to the low amount of resources accumulated to this purpose. When ICT instead did deliver a large growth dividend, this was in correspondence of buoyant ICT investment, rapid fall in ICT prices and high growth rates of capital stocks.

This signals no major evidence of either wasted or prodigiously productive ICT investment in any particular country, with one notable exception. Rates of return on investment did make some difference for Ireland. The average imputed net rate of return in Ireland was 8.5 per cent in nominal terms and 5.9 per cent in real terms, after taking out GDP deflator inflation. This is a relatively high real rate of return within the sample. Comparing Ireland with Finland conveys precisely the importance of rate of return differentials.

Finland invested roughly the same fraction of GDP in ICT capital goods as Ireland. It also started from similarly poor ICT capital endowment in the early 1990s. But Finland obtained a clearly smaller growth contribution from ICT than Ireland; 0.45 rather than 0.64 percentage points per year in 1991-99. This has (also) to do with its smaller real rate of return (4.4 per cent), as well as with its much lower growth rates of ICT capital stocks.

To sum up, it is hard to escape the conclusion that, despite the catching-up in ICT diffusion experienced by most EU countries in recent years, information technologies have so far delivered little aggregate productivity gains in Europe. This is the productivity paradox currently facing Europe.

5 Comparison with previous studies

In the last few years, evidence from aggregate, sector and firm-level studies on the role of information technology in other countries than the United States has slowly accumulated.

Schreyer (2000) first provided some figures for the contribution of hardware and communications equipment capital for the G-7 countries in 1990-96. Daveri (2000) computed the growth contributions of the three ICT capital goods for eighteen OECD countries in 1991-97. In a previous study focussed on the EU, Daveri (2001a) computed the growth contributions of ICT capital for fourteen EU countries in

1991-99.[12] All of these studies took advantage of WITSA data. More recently, Colecchia and Schreyer (2002) repeated the same experiment drawing to a greater extent on national accounting data for nine OECD countries (five in the EU).[13] Roeger (2001) calculated the full contribution of ICT capital to growth by appending some estimates of the enhanced TFP growth counterpart of ICT capital accumulation from privately-sourced ICT production data.

In parallel, a number of national studies aimed at measuring the contribution of ICT to growth in European countries from aggregate data have become available. Oulton (2002) calculated growth contributions for the UK, Cette, Kokoglu and Mairesse (2000) and Crépon and Heckel (2002) for France, RWI and Gordon (2002) for Germany, Jalava and Pohjola (2001) and Niininen (2001) for Finland and van der Wiel (2000) for the Netherlands.

A systematic comparison of previous studies and in particular a full-fledged analysis of why different authors may come to different results is beyond the scope of this study. In what follows, the findings in Daveri (2001a) are picked as a benchmark. This is the only available paper where results for all of the EU countries are provided, while making it clear the list of assumptions needed to compute such growth contributions. These benchmark results are carefully compared with those obtained in Colecchia and Schreyer (2002) and in other individual country studies. The comparison is in terms of real GDP growth (see equation (1)).

Table 4 provides some elements to compare. In general, the growth contributions computed in Daveri (2001a) tend to be larger in size, for various reasons.

The spanning period of the analysis is a first reason. Five-year averages are computed over 1991-95 and 1996-99 in Daveri (2001a), while most other studies compute them over 1990-95 and 1995-99 or 1994-98. By itself, this makes the ICT growth contributions computed in my paper higher than otherwise, given that such contributions have been on the rise during the 1990s. This is not all, though. In spite of their roughly similar methodologies of analysis, a variety of implementation differences (concerning average service lives, depreciation and age-related efficiency loss rules, inclusion/exclusion of software and, crucially, raw nominal investment data) concurs to determine the different results reported in Table 4.

12 In a companion paper, Daveri (2001b) also looked at the employment effects of such growth contributions.

13 I quote their words: ‘Whereas Schreyer (2000) and (Daveri (2001a) use a private data source to assess the size of ICT investment at the international level, the present study is based on data that has recently become available in statistical offices national accounts’. This applies in particular to software data. It is instead a rather inaccurate description of what they have for hardware and communications equipment. As honestly added by the authors: ‘Estimates were still necessary, in particular to obtain long time series’. In particular, their results hinge on ‘OECD estimates’ of business sector IT investment within the overall item ‘IT investment of the total economy’ at current prices for Germany, Italy, and the UK. Even for Finland, data for hardware and communication equipment are OECD estimates rather than national accounting data. These pieces of information are reported in Table 1 of their study.

Table 4
The growth contributions of IT capital goods: comparing the results of various studies

		Daveri (2001a)	Colecchia-Schreyer (2002)	
		1991-95, 1996-99	1990-95, 1995-99	National studies
USA	1990s, 1st half	0.53	0.43	0.57 (Oliner and Sichel, 1991-95)
	1990s, 2nd half	1.45	0.86	1.10 (Oliner and Sichel, 1996-99)
UK	1990s, 1st half	0.43	0.27	0.36 (Oulton, 1989-94)
	1990s, 2nd half	1.17	0.47	0.57 (Oulton, 1994-98)
Sweden	1990s, 1st half	0.38	-	-
	1990s, 2nd half	0.85	-	-
Spain	1990s, 1st half	0.38	-	-
	1990s, 2nd half	0.34	-	-
Portugal	1990s, 1st half	0.39	-	-
	1990s, 2nd half	0.49	-	-
Netherlands	1990s, 1st half	0.65	-	0.20 (van der Wiel, 1991-95)
	1990s, 2nd half	0.72	-	0.23 (van der Wiel, 1996-99)
Italy	1990s, 1st half	0.28	0.21	-
	1990s, 2nd half	0.35	0.36	-
Ireland	1990s, 1st half	0.38	-	-
	1990s, 2nd half	0.96	-	-
Greece	1990s, 1st half	0.25	-	-
	1990s, 2nd half	0.46	-	-
Germany	1990s, 1st half	0.54 *	0.30	0.44 (RWI and Gordon, 1990-95)
	1990s, 2nd half	0.45	0.35	0.45 (RWI and Gordon, 1995-00)
France	1990s, 1st half	0.40	0.18	0.17 (Cette *et al.*, 1989-95) 0.32 (Crèpon *et al.*, 1987-98)
	1990s, 2nd half	0.44	0.33	0.27 (Cette *et al.*, 1995-99)
Finland	1990s, 1st half	0.21	0.24	0.3 (Jalava and Pohjola, 1990-95)
	1990s, 2nd half	0.74	0.62	0.7 (Jalava and Pohjola, 1995-99)
Denmark	1990s, 1st half	0.42	-	-
	1990s, 2nd half	0.65	-	-
Belgium	1990s, 1st half	0.48	-	-
	1990s, 2nd half	0.49	-	-
Austria	1990s, 1st half	0.47	-	-
	1990s, 2nd half	0.43	-	-

Note: * 1992-95

The most relevant discrepancies regard the UK and, to a lesser extent, the Netherlands and France. Daveri (2001a) found evidence of sizeable progress in the extent of adoption of ICT and the growth contribution from ICT goods in the UK. Oulton (2002), combining the latest national accounts figures and personal estimates of the contribution of software, comes up with smaller figures, in particular with a much smaller increase in the contribution of ICT capital in the second half of the 1990s. This has partly to do with the fact that Oulton's data stop in 1998, but also, and more crucially, on substantial differences between WITSA and Oulton in the estimated growth rates of software investment and capital. Colecchia and Schreyer (2002) combine Oulton's data with some OECD estimates and (expectedly) obtain results similar to Oulton.

As to the Netherlands and France, the differences with the results in van der Wiel (2000) and Cette, Kokoglu and Mairesse (2000) are more on the average levels than on the time variations of growth contributions. My result of a growth contribution of ICT capital of about 0.65 percentage points in the Netherlands is bigger than the one found by van der Wiel (2000), but the change in the growth contribution of ICT over time is similarly very small in both studies. The same applies when comparing results for France.

As to the remaining EU countries for which a comparison can be drawn (Finland and Germany), the results in Daveri (2001a) are, in fact, not too far apart from those obtained in other studies. In particular, as apparent in Table 3, the jump in the ICT contribution in Finland and its substantial constancy calculated for Germany across the two halves of the 1990s hold across studies.

In most papers, the contribution of ICT capital to growth is evaluated within a traditional growth accounting framework, i.e., under the assumptions of constant returns to scale and perfect competition in factor and goods markets. A variety of papers exists where firm-level data are employed to study non-neoclassical effects[14] of ICT capital on TFP growth (see the survey by Brynjolfsson and Hitt (2000). This is not done here, as well as in any other cross-country and national study implemented with non-US aggregate data so far. Stiroh (2002) provides a quantitative evaluation of such effects with US aggregate data. Using sector data for a number of OECD countries, both van Ark (2001) and Pilat and Lee (2001) found a significant confirmation of the existence of productivity spillovers, mainly from ICT producers to ICT users, as usually defined by OECD.

To sum up, the actual extent of the growth effects of information technologies in Europe may remain debatable. Yet the overall picture to be drawn from the available aggregate data is not. In spite of the acceleration of the catching-up in ICT diffusion experienced by most EU countries in recent years, information technologies have so far delivered limited productivity growth gains.

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14 'Non-neoclassical' effects materialize when investment (e.g. IT investment) at the firm level positively affects the efficient operation of other firms as well, i.e. when investment generates a positive technological externality.

6 Conclusions

The evidence on the new economy in Europe presented in this paper pertains to two separate issues: the extent of diffusion and the growth effects of information technologies.

ICT spending and investment data show that the European Union as a whole lagged behind the United States throughout most of the 1990s, but then partially caught up in 1998-2001. As of 2001, about two-thirds of the EU population got much closer to US levels of ICT adoption. The remaining third of the EU citizens clusters together in a group of 'slow ICT adopters' (inclusive of Ireland, Italy, Spain, Portugal and Greece), whose distance in ICT diffusion from the US and the other EU countries has not decreased or even widened over time.

Not much has been witnessed, however, as to the closing of the EU productivity growth gap with the United States. In Europe, unlike the US, there was no such a thing as productivity growth acceleration in the second half of the 1990s.

This leaves room for speculating on what—if anything—went wrong in Europe. A first possible answer is: nothing. 'Lagging behind', i.e., a slow pace of adoption of a new technology, may be a good thing. If a country is internationally specialized in the production of low-tech goods, investing in high-tech goods may go against comparative advantage considerations. Moreover, as long as the process of adoption of a new technology involves trial and error, there may not be a first mover advantage in adopting the new technology. Instead, learning from other people's mistakes may save waste in resource allocation, as long as first-comer's learning is easily transferable to the follower. If this is the story, then Europe did not lag behind; rather, the US accumulated too much of ICT goods, with 'irrational exuberance'.

A second option is that ICT adoption in Europe was instead sub-optimally hampered by some policy-induced impediments. As emphasized by Gruber and Verboven (2001), technological and institutional obstacles retarded the diffusion of mobile telecommunications services in the EU. More generally, Bassanini and Scarpetta (2002) argue that anti-competitive forces affecting labour and product market regulation clearly reduced TFP growth and ICT diffusion in the OECD countries. Without such policy impediments, the way towards a faster adoption of information and communication technologies *and* higher productivity growth would have been eased. More research is needed to achieve a better understanding of such questions.

How about the future of productivity growth in Europe? The latest aggregate evidence presented in this paper suggests that lags in ICT adoption may no longer be a major issue in about two-thirds of the EU. The crucial issue for Europe in the next few years is not how to speed up investment in new technologies, but rather how to make them work. Europe has primarily to come to grips and solved its 'Solow paradox'.

Even so, there are two reasons to be moderately optimistic about the future of productivity growth in Europe.

First, it may simply be too soon to judge. Information technologies are pervasive (general-purpose) technologies bound to spread in the economy, but this requires some time, as suggested by Greenwood and Jovanovic (1999) and David (2000), among others. If the costs of adjusting to a new technology are substantial, along the time interval between their introduction and their effective adoption, productivity growth may suffer a shortfall. This would explain why the catching-up in ICT diffusion has not raised productivity growth yet. If this is the case, the productivity-enhancing effects of the ICT acceleration of the late 1990s are still to be seen in Europe.

Second, in spite of the recent catching-up in spending and investment, the value added share of ICT capital remains much smaller in the EU than in the US, as a result of the persisting investment gap in the 1990s. Along the same lines of reasoning as in Jorgenson, Ho and Stiroh (2001) and Oliner and Sichel (2002) for the US and Oulton (2002) for the UK, there is some scope for Europe's growth contribution from ICT capital to continue to go up and further contribute to aggregate growth in the future, even in the absence of ever accelerating accumulation rates of ICT capital.

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Appendix

A1 How ICT capital stocks are computed

The provision of quality-adjusted price indices for investment provides a natural weighing scheme of different investment vintages for the perpetual inventory method. As long as quality improvements are accounted for on the price side, investment flows can be recursively added up after allowing for the loss in productive efficiency of each capital good over time. The specific rule chosen here implies that the marginal efficiency loss increases over time. This is line with the evidence provided by Whelan (2000) for the United States. The loss of productive efficiency is assumed to be zero in the early years of life of an ICT capital good. This initial 'grace period' is, respectively, three, four and five years for software, hardware, and communication equipment. Then the efficiency loss goes up at an increasing rate as the capital good 'ages'.

To calculate capital stocks for all ICT items throughout the 1990s, the perpetual inventory method requires investment series go back to 1984 for hardware, 1987 for software, and 1980 for communications equipment, depending on their respective service lives.[15] Since WITSA data are only available through 1992-99, investment data for the missing years have to be projected backwards.

As in Caselli and Coleman (2001), the unobserved growth rates of the GDP shares of ICT investment were approximated by the growth rate of the GDP shares of the corresponding ICT-related imports. The growth rate of the GDP shares of computer imports, as reported in Caselli and Coleman (2001), was taken to proxy hardware spending. As to software, I picked the growth rate of the GDP share of 'communications, computer, information, and other services', from the *World Development Indicators* of the World Bank. The import shares of telecommunications equipment reported in the OECD 2000 Telecommunications Database were taken to proxy investment in communications equipment. Data for 1980-91 for Germany refer to West Germany.

A2 How rates of return and value added shares were computed

Following Hall and Jorgenson (1967) and Oliner and Sichel (2000), equation (3) in the main text can be used to infer a value for r, and then, in turn, for the value added share of each capital good k. From Fraumeni (1997) and Seskin (1999), yearly depreciation rates of 32 per cent, 44 per cent and 15 per cent are imputed to hardware, software and communications equipment. In other words, ICT capital depreciates much faster than the aggregate capital stock, whose depreciation rate is 7.5 per cent

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15 Fraumeni (1997) and Seskin (1999) calculated that the average service lives for US hardware, software and communications equipment are, respectively, seven, four and eleven years. Assuming that: (a) these figures also apply in the other countries in the sample, (b) deterministic retirement occurs at the end of the service life of a capital good, and (c) investment at time t enters the capital stock at the end of time t, the dates reported in the main text obtain. Assumption (c), in particular, is not the usual practice in national accounting, where a gestation lag of one year is customarily assumed. This practice is less justifiable, though, when dealing with such capital goods as software and computers. As Jorgenson and Stiroh (2000), I omitted the gestation lag.

per year. The 7.5 per cent depreciation rate is the weighted average of the depreciation rates of 25 equipment goods and 18 structures listed in Fraumeni (1997). Residential buildings are left out. The rates of change of P_k can be approximated by three-year moving averages of the growth rates of each investment deflator (Both P_k and r are specified in nominal terms.) Capital-output ratios are obtained from the perpetual inventory method, once nominal rather than real investment is used. Finally, the 'other capital' item is computed residually. Capital stocks data for hardware—evaluated, following Schreyer (1998), at quality-unadjusted prices—and communications equipment are thus subtracted out of aggregate capital stocks, and the 'other capital' item is obtained.

Having done so, the net rate of return is obtained from the identity: $s_K = s_{COM} + s_{HW} + s_{OTK}$ (software is not subtracted out, for it is still excluded from the OECD measure of aggregate capital stock), under the restriction that the same rate of return r be earned on all types of capital. Once the aggregate share s_K is computed from aggregate data, each of the three shares depends on the net rate of return r only, that can be computed right away. In turn, once the net rate of return is calculated, the gross rate of return on each capital good and its income share derived as well.