Information Technology and Growth in Europe

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This paper documents the extent of adoption and the growth contribution of information technology (IT) capital in the European Union in the 1990s. Not only are IT spending and investment much smaller in the EU as a whole than in the US, but this gap has also widened over time. Cross-country asymmetries in IT adoption are also, and crucially, sizeable within the EU, though. 'Front-runners' (UK, Netherlands, Sweden, Ireland) are not far from the US, while the rest of the EU countries substantially lags behind. Differences in IT investment and accumulation rates have a close counterpart in the computed growth contributions from information technologies, except for Ireland. The observed overall growth gaps can be, to a non-negligible extent, associated to cross-country gaps in IT adoption and contributions.

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1. Introduction

The return to growth of the US economy in the 1990s and, in particular, its growth acceleration in the second half of the decade are mostly credited to the increased contribution of information technologies (IT).[1] A crucial issue is whether information technologies may enhance growth prospects in Europe too. This question is addressed here by documenting the extent of adoption and the growth contribution of information technology (IT) capital in the European Union in the last decade.

In the first part of this paper, data from a private source (WITSA, 2000) are exploited for a systematic comparison of IT diffusion in the European Union and the United States. The depth of adoption of information technologies is measured as the fraction of spending and investment in hardware, software and telecommunications over GDP. Available evidence points to substantial differences in the extent of IT adoption between the EU and the US, but also, and crucially, within the EU. Throughout the 1990s, spending in hardware, software, communications equipment and other IT services was less than 6% of the EU GDP and about 8% of the US GDP. Investment was 2% of the EU GDP and almost 3.5% of the US GDP. Crucially, however, both spending and investment gaps have indeed risen over time.

Yet a closer look at IT data also shows that the information technology gap does not concern all of the EU countries. The extent of IT adoption in Sweden, the UK and the Netherlands does not markedly differ from US standards. Instead, four (Germany, France, Italy, Spain) of the large countries in the Union clearly lag behind compared to the US and to Northern Europe.

The second important aspect of the paper is the calculation of the growth contributions of IT capital in Europe within a standard growth accounting framework. In the UK, the Netherlands, Ireland and Sweden, the IT contribution to growth was between two thirds and three fourths of one percentage point per year - the average yearly figure computed for the US in the 1990s. At the bottom end of the country

[1] While controversies exist on the permanent or temporary nature of the 1990s growth resurgence (see Gordon, 2000), the consensus on the crucial role played by information technologies is wide-ranging. Oliner and Sichel (2000) and Jorgenson and Stiroh (2000) have found evidence that the growth contribution of information technologies was small (0.2-0.3 percentage points per year) in 1974-95, with a marked rise of this contribution to a full percentage point in 1996-99.

ranking, IT contributions were, instead, as low as 0.3 percentage points per year in Greece, Italy and Spain, with the rest of European countries in between.

The evidence brought about in this paper also speaks to a variety of other important empirical questions dealt with in past research. I list three of them.

First, cross-country differences in IT growth contributions are, as a rule, a close counterpart of differences in IT capital accumulation rates. At least for Ireland, though, above-average rates of return on investment also appear to have played a role.

Second, previous US studies have found that hardware provides the bulk of the calculated contribution of IT capital. The same applies to European countries. In addition to that, however, the contribution of telecommunications is relatively smaller, and the contribution of software relatively larger, in countries where IT diffusion is highest. This is suggestive of a gradual shift into a 'weightless' economy as IT adoption proceeds.

Finally, the Oliner-Sichel question on how important IT is in accounting for growth is raised in a cross-sectional framework. I find that a non-negligible - though varying between 25% and 90% - fraction of the EU growth gap with the US is explained by IT capital accumulation. Hence, cross-sectional growth gaps in the 1990s were, to some extent, an information technology story too.

The structure of the paper is as follows. The methodological and measurement issues involved in the construction of investment flows, price deflators, capital stocks and income shares of IT goods in Europe are discussed in Section 2 and in a Data Appendix. This is important for the results summarised above ultimately draws on a private data source, whose data collection methodologies do not fully conform to national accounting criteria. The evidence on the extent of adoption of information technologies and the growth contributions of IT capital in Europe is presented, respectively, in Section 3 and 4. In Section 5, the results of this paper are paralleled to earlier findings. Section 6 concludes.

2. Data and measurement issues

The crucial preliminary question to address is whether reliable cross-country data to evaluate the depth of adoption and the growth implications of information technologies exist at all.

In the US, following a decade-long process of data revision, [2] the Bureau of Economic Analysis at the Department of Commerce regularly releases chained real investment data and hedonic (*i.e.* quality-adjusted) price indices[3] for hardware, software and communications equipment. The picture is tremendously different for Europe. Scarpetta, Bassanini, Pilat, and Schreyer (2000, pp.89 and 92) report that only a handful of countries in Europe employ quality-adjusted price indices and chained methods in computing their real GDP. [4]

Before presenting the evidence brought to bear in this paper, it is thus particularly important to carefully think about data and measurement issues.

2.1 Data source and collection methodology

Absent official data, the private source of primary data employed here is WITSA (2000). In its *Digital Planet 2000*, WITSA [5] published IT spending data for the fifty largest markets in the 1990s. These data originate from the work of data collection undertaken by IDC (International Data Corporation, a private consulting company specialised in high-tech industries research) on behalf of WITSA. This is the only source of consistent information technology data for a large cross-section of countries in the 1990s.[6]

IDC data collection takes place both at the individual country level and at corporate headquarters. 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 the IDC headquarters and regional research centres, and cross-checked with global vendor census data. Vendor data are then supplemented by user interviews and surveys.

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[2] The US Bureau of Labour Statistics (BLS) and the Bureau of Economic Analysis (BEA) have undertaken an impressive work of data revision since 1985. Hedonic (*i.e.* quality-adjusted) price indexes for computers and semiconductors were constructed by the BEA. Broadly speaking, this has redistributed the nominal growth of computer-related incomes away from prices to quantities. The price index of semiconductors – a key input in computer production - was adjusted for quality as well, which helped achieve a sensible balance between cost and revenue effects of quality improvements over time. Finally, the traditional fixed-weight indexes were supplemented by chained price indices. See Moulton (2000) for a concise rendition of the main methodological changes entailed by this revision.

[3] A survey of the research on hedonic pricing is in Triplett (1989).

[4] Hedonic prices for computers are computed in Denmark, France and Sweden. Denmark actually converts the US price index into Danish Crowns right away. Real GDP growth is computed through yearly-adjusted weights in France, Greece, the Netherlands and Portugal only.

[5] WITSA is the World Information Technology and Services Alliance - a consortium of 48 information technology industries associations around the world.

IDC does not publicly release other pieces of information as to the size and structure of its sample. The degree of comprehensiveness of the IDC survey remains therefore hard to gauge to an outside observer. In spite of this shortcoming, both the OECD (see OECD (1999) and Schreyer (2000)) and Eurostat (2000) have used IDC data to monitor the evolution of the IT market. Absent comparable official data, I do the same here.

2.2 Definitions

IT Spending. WITSA/IDC spending data concern sales of hardware, software and related external and internal services, plus telecommunications. 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. IT 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. IT software spending includes the purchase 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 customisation of computer programmes, *i.e.* own-account software in the BEA terminology.

Telecommunications. Telecommunications spending includes expenditures on public network equipment (such as switching, transmission and mobile communications infrastructures), private network equipment (such as PBXs and key systems, telephone sets and mobile equipment) and telecommunications services (such as fixed and mobile telephone services, switched data and leased line services, cable TV services).

IT investment To calculate business sector investment in hardware, software[7] and communications equipment, household and government spending are to be subtracted out of total spending. Unfortunately, within the broad WITSA/IDC spending item, the distinction between private and public spending, as well as between the household

[6] Data from the EITO (European Information Technology Observatory) Yearbook are available as well. Yet EITO does not publish a consistent time series of IT data.

and the business sector, cannot be recovered. Then, I imputed myself a fraction of total spending to business sector investment, by computing the 1992-99 average ratio between business sector investment and the corresponding WITSA spending item for the United States. BEA hardware investment turns out to be about 58.6% of total hardware spending. BEA communications equipment is about 31.6% of total telecommunications spending. BEA software investment (inclusive of own-account software) is about 212.5% of the WITSA software item. These coefficients are then multiplied by the corresponding WITSA spending items for EU countries to derive nominal IT investment spending data in 1992-99. OECD and World Bank data on IT import shares were then used to project backwards such investment data. This is to obtain series long enough to calculate capital stocks in the 1990s through the perpetual inventory method. As in Caselli and Coleman (2001), the unobserved growth rates of the GDP shares of IT investment are approximated by the growth rate of the GDP shares of the corresponding IT-related imports (see the details in the Data Appendix).

IT 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. Exploiting the high tradability of IT goods, I assumed that the PPP property in weak form holds for each It good. Then, the rate of change of the computer price in Italy was approximated by the sum of the rate of change in the price of computers in the US, and the devaluation rate of the US$ with respect to the Italian Lira. The same applies to other countries and currencies. Research by Moch (1999) and Moreau (1997) on the prices of personal computers in Germany and France suggests that EU prices are declining as fast as in the US.

Real investment data are computed by dividing nominal investments by the price indices obtained as above.

2.3 Are available data good indicators of IT spending and investment ?

As emphasised in the previous sub-section, a full set of comparable cross-country data for information technologies is unavailable. Deriving some of the series involves some untested assumptions. This may bias both IT investment series as well as the

[7] The treatment of software as an investment, rather than an intermediate, good is another instance of the major revision of national accounts undertaken by the US BEA.

results of the growth accounting exercise. It would thus be desirable to be aware of the direction of these distortions.

Whether the contribution of computers to growth was correctly measured has been a matter of discussion for a long time in the United States. Quantifying the 'quality bias' of the estimates of productivity growth - a special case of the problem of valuing new goods - has attracted a great deal of attention. [8] Siegel (1997) provided evidence that the quality bias associated to the introduction of any new good is exacerbated for computers. This bias distorts conventional estimates of the marginal productivity of computers downwards, and may, therefore, be associated to the celebrated Solow's 'productivity paradox'. This is exactly what 'hedonic pricing' techniques are for: eliminating or, at least, lessening the quality bias. As extensively discussed by Jorgenson (2001) and others, the calculation of quality-adjusted price deflators is usually restricted to a few items even in the United States. This is a source of bias, as long as quality improvements concern other items and sectors in the economy, whose prices are not adjusted.

These measurement problems are compounded here with other measurement issues induced by the very imperfect cross-country comparability of WITSA/IDC data. [9]

1) *Incomplete coverage of WITSA data.* IT spending of unincorporated enterprises is just left out of WITSA nominal spending data. This downward biases nominal investment data, in particular for those European countries, such as Italy, Greece, Spain and Portugal, where small-sized enterprises disproportionately contribute to output and employment.
2) *Backward projection of IT investments* The methodology of backward projection of IT investments from official IT imports data (see the Data Appendix) likely understates the investments in information technologies of IT-producing EU countries (Finland, Ireland, Sweden) in the 1980s. This effect is also presumably more important for long-lived capital goods, such as hardware and telecommunications equipment, than for software.
3) *Deviations from the PPP.* If relevant obstacles to commerce exist, the PPP (in weak form) assumption necessary to infer IT prices in the EU directly from US IT

[8] Van Ark, Monnikhof and Mulder (1999)c studied how problems in the measurement of value added in the sectors most heavily using IT goods make it hard to evaluate sector findings on the lack of correlation between IT investment and TFP growth. Diewert and Fox (1999) spelled out at length how accounting and economic mis-measurement may have caused the productivity slowdown in the 1970s.

prices would further bias real investments upwards for the countries where IT deflation is over-estimated.

4) *Fixed-weight calculation of GDP.* Any overstatement of IT price deflation results in an upward bias of real investment series. In turn, this probably exaggerates the growth contribution of IT goods in the European countries where GDP and investment data are not calculated through variable weights. Hence, the likely exaggeration in the dynamics of real investment in IT goods possibly magnifies the growth contribution of IT capital, of hardware in particular, with respect to other items.

In conclusion, the use of unofficial cross-country data for IT goods expectedly adds novel measurement issues to those already emphasised in the US literature. It remains hard to draw firm conclusions as to the overall direction of the various distortions.

3. The extent of adoption of information technologies in the European Union

3.1 IT Spending

According to WITSA (2000), the world market for IT products – as measured by the total spending in IT products and services – totalled 2.1 trillion US$ in 1999. IT spending in the United States and Europe reached, respectively, 0.8 and 0.5 trillion US$ - about 38% and 24% of the world IT market.

Table 1 points to a gap in the use of information technologies between the US and the European Union. This is seen immediately apparent when comparing GDP and IT world shares of the US and Europe. The EU enjoys a large share of the world IT market, but its IT market share is smaller than its share in the world GDP. The opposite holds for the United States. Moreover, this gap has even widened over time. The EU share in the world GDP has declined by five percentage points in seven years. Yet its share in the world IT spending has declined even more - by almost eight percentage points. The US shares over both world GDP and IT spending have instead gone up, with the IT share growing relatively more.

[9] The implications of different measurement methodologies for cross-country comparability of labor productivity data were first documented by Wyckoff (1995).

The EU-US gap in IT usage can also be described in terms of the GDP shares of IT spending – an index of the depth of adoption of information technologies in a country. **Table 2** shows that information technologies have absorbed a smaller GDP share in Europe than in the United States (respectively, 5.7% and 8.0%) in the 1990s. [10] While IT expenditures rose in both areas, the spending gap grew by half a percentage point, from 2.1 in 1992 to 2.6 percentage points in 1999.

Nevertheless, exclusively focussing on the EU-US dichotomy is too crude an approximation for the variety of experiences in IT adoption observed in Europe in the 1990s. A closer look at spending data by country, still based on **Table 2**, helps amend this gross picture.

In 1999, two EU countries (Sweden and the UK) spent a larger fraction of their GDP in information technologies than the US. The Netherlands, Denmark and Ireland also spent in IT more than the EU average, with Finland and Belgium coming close to it. In the same year, at the bottom end of the country ranking, Spain and Italy devoted only about 4% of their GDP to information technologies – two points less than the EU average and about half as much as the US, Sweden and the UK. In between, France and Germany spent, on average, one percentage point more than Italy and Spain, but, strikingly, their IT spending shares did (slightly) fall over time. Spending shares fell in Spain and Austria too.

In conclusion, the alleged EU-US gap is rather a gap between most countries in Continental Europe and both the US and Northern Europe.

3.2 IT investment

The IT investment picture is not dramatically different from the one drawn for total spending. **Table 3** reports data on the GDP shares of IT and total fixed investment in 1992 and 1999, as well as on their changes over time. All data are in GDP nominal shares.[11]

[10] Is this gap large or small ? I claim it is large. Suppose that, in the future, the IT spending share grows in the European Union at the same pace as in 1992-99. How long would it take for the EU to reach the same IT spending share as the US today (*i.e.* 8.63% of GDP) ? The answer is: approximately 28 years. What if the pace of introduction of information technologies in the EU speeds up and reaches the pace enjoyed by the US in 1992-99? Even in this optimistic case, it would still take about 16 years for Europe to reach the current level of IT usage in the United States. This suggests that the EU-US gap is large.

[11] On the conceptual difficulties of using real shares with chained data see Whelan (2000b, p.11).

About 4.5% of the US GDP – more than 50% of total IT spending - was invested in information technologies in 1999, up by 1.9 percentage points since 1992. The European Union as a whole has increased investment spending as well to 2.4% of its GDP, about 40% of total IT spending and up by a bare 0.6 percentage points since 1992. The EU-US investment gap does not just concern the amount of resources invested, but also the propensity to invest for a given amount of spending. It has grown over time, and its increase has been bigger than the rise in the spending gap.

Similarly to spending, however, aggregate data for the EU mask important cross-country differences in investment rates. Significantly, no country in Europe has invested in information technologies more than the US in the 1990s. A group of front-runners (Sweden, the UK and the Netherlands) invested 3% or more of their GDP in information technologies in 1999. Spain, Greece, Portugal, Italy and Austria invested in IT capital less than 2% of their GDP, with the other countries in between.[12]

To check whether the computed investment series makes sense, I calculated the correlation between the GDP share of IT investment and the fraction of networked PCs over the total PC population (source: WITSA). The contemporaneous correlation turns out to be quite high (ρ=0.86), and remains about that high, irrespective of the specific year considered, and irrespective of leads and lags. This is evidence of a solid cross-sectional correlation between these two variables. The correlation between IT spending and the share of networked PCs is high as well, but smaller (ρ=0.75) than the one computed for investment.

It is also instructive to consider how important is IT investment with respect to total fixed investment. In all European countries, IT investment has become a larger fraction of total investment in 1999. In the EU as a whole, it went up to 11.5% of total investment in 1999, up from 7% in 1992 (see column [4], [5] and [6] in **Table 3**).

Sweden and Ireland represent two polar cases. In Sweden, aggregate investment declined in parallel with the boom in IT investment. In Ireland, just the opposite occurred. Once considered jointly with total investment, even the modest increases in IT investment in France, Germany and Italy look less modest than at first sight.

[12] Are these differences large or small ? Based on the EU average investment rise of 0.6 percentage points in seven years, the answer is: they are large. It may take as long as 17 years, for Spain to go up from its 1999 investment share of about 1.6% of GDP to the Dutch 1999 share of 3.1 percentage points. Would Spain increase its investment share at the same pace as Greece or Sweden in 1992-99 (+1 percentage point overall), then the period of time to reach 3.1 percentage points would shorten to about eight years.

3.3 IT prices, real investments, capital stocks, rates of return and value added shares

The growth rates of IT nominal investments in hardware, software and communications equipment can be decomposed into their price and quantity counterparts. **Table A1** reports the rates of change of the price indices constructed as described in Section 1 and the real investment flows of each IT capital good, relatively to the 1991-99 period.

Table A1 replicates some well-known US results. As to hardware, in the 1990s the sharp fall in prices (-18.5% per year) had a counterpart in terms of extremely high growth rates of real investments (+38% per year). The price reduction of software and communications equipment was instead less pronounced, partly as a result fo the limited coverage of the application of hedonic pricing techniques. Investments in these capital goods rose substantially as well, but at smaller rates than hardware.

Very similar trends are present for EU countries as well, in spite of the cross-country discrepancies in IT nominal investment previously emphasised. Rates of change of price and quantity of hardware investment are clearly negatively related (the coefficient of correlation across countries is about 0.4). The same pattern of correlation is also present for software, while the price-quantity correlation for communications equipment is near to zero. Real investments in software and communications capital rose less than hardware in nearly all countries.

High growth rates of real investments translated into correspondingly high growth rates of IT real capital stocks, much higher than the growth rates of aggregate capital stocks (see **Table A2**).

In turn, the fast growth of IT capital stocks translated into rapidly rising capital-output ratios and value added shares of IT capital. Even so, in 1999, IT capital still represents a rather modest share of total capital in all countries, including the US. As shown in **Table A3**, the IT capital-output ratio in the US was about 0.18, slightly higher than in the UK and Sweden, the Netherlands and Finland, and about twice as much as in Greece, Italy, Spain and Portugal with the rest of the EU countries in between. These figures contrast with values of the aggregate capital-output ratios for the business sector (or the overall economy) ranging between two and three.

IT capital accumulation was instead rapid enough to generate marked increases in the shares of value added appropriated by IT capital. In the US, the value added share of

IT capital has reached 0.08 in 1999 – 0.029 to hardware, 0.034 to software and 0.016 to communications equipment. [13] A value of 0.08 is about one fifth of the value added share (augmented of the software share) allocated to aggregate capital in the US. In Europe, IT capital appropriated about 6% of total value added in Sweden and the UK, 5% in Ireland and the Netherlands, down to some 3% in Italy, Germany, France, Spain and 2.5% in Portugal and Greece. In Greece, Italy, Spain and Ireland, communications equipment absorbed about 40% of the IT capital share on value added. In most other countries, the distribution of value added to the various IT goods was more similar to the one recorded in the US, with the biggest chunk of it destined to hardware and software.

Finally, the calculated value added shares for IT goods embody values for the gross and the net nominal rates of return imputed as spelled out in the Data Appendix. The 1991-99 average values of these returns are reported in the last column of **Table A3**. Gross rates are relatively similar across countries and sharply different across types of goods. Software and hardware exhibit the highest gross rates of return, and communications equipment the lowest. [14]

3.4 Summing up on the extent of IT adoption

Evidence on IT spending and investment points to substantial differences in the depth of adoption of information technologies between the United States and the European Union, but also, and crucially, within the EU.

Throughout the 1990s, the EU spent and invested in hardware, software and communications equipment much less than the United States. Both expenditure and investment gaps have even gone up over time.

Yet a closer look at IT data shows that the information technology gap is not there for all of the EU countries. The extent of information technology adoption in Sweden, the UK and the Netherlands does not markedly differ from US standards. Some countries in the EU (Italy, Spain, Greece and Portugal) clearly lag behind instead, with France and Germany in between. The worrisome feature for the EU as a whole is that four

[13] Oliner and Sichel (2000) report values of 0.018 for hardware, 0.025 for software, and 0.020 for communications equipment.

[14] These results are ultimately driven by the assumptions on depreciation rates, constant across countries and sharply different across goods. See the Data Appendix for details.

(Germany, France, Italy, Spain) of its largest countries belong to the group of the laggards.

4. The growth contribution of information technologies in the EU

4.1 The growth accounting framework

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 mentioned papers by Oliner and Sichel, as well as Jorgenson and Stiroh, are the latest examples of this strand of literature. This paper too is a contribution within this tradition.

The exercise conducted here 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-IT productive capital. The decomposition of growth contributions by input, under the standard assumptions of constant returns to scale and perfect competition, is the following:

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

where s_C is the capital income share of capital good C (C= COM, HW, SW, OTK) averaged over time t and $t-1$; s'_K is equal to s_K, the capital share computed from national accounts, with the standard correction for self-employment [15] and augmented

[15] '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.

of s_{SW}, the software share[16]; 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-IT) capital, and the well known 'Solow residual', a residual item supposed to measure disembodied technical change.[17]

Within a growth accounting framework, the effective adoption of IT capital is simply determined by the product of the rate of accumulation and the value added share of each IT capital good. Factor shares in value added are computed (see (2) in the Data Appendix) multiplying the gross rate of return on investment in the specific IT capital good by the ratio between its capital stock and GDP. The growth contribution from IT goods may thus be high or low for three reasons: *(i)* fast capital accumulation, *(ii)* a high gross rate of return, *(iii)* a high capital-output ratio.

4.2 Results from growth accounting

In this sub-section, accounting results for information technology capital goods are presented first. Then it is asked whether cross-country differences in growth contributions are mainly determined by differences in accumulation rates or value added shares. Finally, results for IT capital are related to the overall decomposition of GDP growth into its labour, capital and TFP components.

4.2.1 The growth contribution of IT capital

Table 4 presents the key growth accounting results in this paper. The computed growth contributions from IT capital in the whole decade and in the two sub-decades are shown in column [1]-[3]. The breakdown of the average IT contributions into their hardware, software and communications equipment components is in column [4]-[6].

It is convenient to start describing US results. IT equipment and software contributed to growth in the US for 0.94 percentage points per year in 1991-99. The 1990s

[16] 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.

[17] GDP, employment, aggregate capital and the capital income shares s_K for the business sector are taken from the OECD Economic Outlook. The average number of hours worked is from Scarpetta, Bassanini, Pilat, and Schreyer (2000, Table A.13, p.83). The TFP computed here also absorbs the changes in the composition of the labor force, which was instead appropriately separated out in other studies, such as Oliner and Sichel's and Jorgenson and Stiroh's.

average was the result of a steadily rising contribution of information technologies, from 0.53 points in 1991-95 to 1.45 points in 1996-99.[18]

As shown in column [4]-[6], the average IT contribution of 0.94 is the sum of half a percentage point from hardware, one third of a percentage point from software and less than one tenth of a percentage point from communications equipment.[19] As previously found in Oliner and Sichel (1994) and Jorgenson and Stiroh (1995), hardware provided the main growth contribution from IT goods in the US. Software and communications equipment, however, count for another 47%. Computers are by no means the only driving force of the US 'information technology & growth' story. Either leaving computers out or exclusively focusing the attention on them would lead to misleading conclusions on the overall relation between information technology and growth.

How about Europe ? The growth contributions from IT capital in all European countries are clearly smaller than the one computed for the US. Nevertheless, within-EU differences are large as well.

The highest calculated contributions in Europe are those recorded for the UK, the Netherlands, Ireland and Sweden. They ranged between two thirds and three fourths of a percentage point per year in 1991-99, about 0.25 percentage points smaller than the US datum. At the other end of the spectrum, information technologies contributed to GDP growth for about 0.3 percentage points per year in Italy, Greece and Spain.

The other EU countries are half-way through. In Germany and France, the two largest countries in Europe, growth contributions averaged 0.5 and 0.4, respectively. In Germany, Austria and Spain, however, IT growth contributions declined over time (see column [2] and [3] in **Table 4**).[20] Quite the opposite, the yearly growth

[18] Oliner and Sichel (2000, Table 1) report values of 0.57 for the growth contribution from IT in 1991-95 and of 1.10 in 1996-99. A presumably important source of the difference between the results reported here and Oliner and Sichel's is the law of accumulation of IT capital. In this paper, as in Jorgenson and Stiroh (2000), today's IT investment immediately enters the stock of IT capital: $K_t=K_{t-1}+I_t$. Oliner and Sichel (2000, Appendix A.c), instead, adopts a more sluggish law of capital accumulation: $K_t=K_{t-1}+(I_t+I_{t-1})/2$. At times when investment is sharply accelerating (as in 1998-99), these two formulations may give rise to sharply different capital accumulation rates. Another implementation difference likely stems from the exact shape of the age-efficiency profiles assumed for the three IT capital goods.

[19] These results are very similar to those reported in Oliner and Sichel (2000, Table 1), where growth contributions of 0.44 for hardware, 0.29 for software and 0.11 for communications equipment were found.

[20] The declining growth contributions from IT in 1996-99 are essentially driven by the sharply declining rates of growth of the capital stocks in communications equipment and software. This is partially a side effect of the assumption of deterministic retirement of IT capital goods (see the **Data Appendix**). Had deterministic retirement been replaced with stochastic retirement around the average

contributions from IT capital rose considerably – roughly by half a percentage point - in Ireland, Finland and Sweden in the same period of time. In the UK, the rise was even bigger (+0.7 points).

Hence, the polar cases in Europe in the 1990s are as distant from each other as the data recorded for the US economy in 1974-90 and in 1995-96. In the years before 1990, the information technology revolution was still in its infancy. Most observers locate the turning point in the US productivity growth rate in 1995-96. This is suggestive of how long it would take to close the IT gaps in Europe.

Table 4 (column [4], [5], [6]) also provides evidence on the breakdown of the IT growth contributions across the various types of IT capital goods. Its main insights are three:

(a) The growth contribution of computers was sizeable in Europe as well, but usually relatively smaller in Europe than in the US.

(b) The relative growth contribution of communications equipment was relatively higher in Europe than in the US, in particular in those countries with a lower degree of adoption of new technologies.

(c) The relative growth contribution of software was lower in Europe than in the United States, particularly in those countries with a lower degree of adoption of new technologies.

In all EU countries, just as in the United States, computers did represent the bulk of the IT growth contribution. In most EU countries, the growth contribution of hardware was between 40 and 50% of the total growth contribution of information technologies. This is a slightly smaller share than 53%, the hardware share computed for the United States. In Sweden, Finland and Denmark, it was slightly higher than in the US.

The lower relative growth contribution of computers is not the only EU-US difference in the breakdown of the IT contributions. The contributions of software and communications equipment were also, respectively, relatively low and relatively high in Italy, Greece, Portugal and Spain. The importance of telecommunications equipment is high (and the importance of software is low) in those countries where the overall adoption and growth contribution of information technologies clearly lags behind compared to the US and Northern Europe.

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service lives, the capital stock would have followed a smoother time trend, possibly levelling off growth contributions in the two sub-periods.

If confirmed in the future, such a trend away from telecommunications towards software would imply that the diffusion of information technologies is really associated with increasingly ‘weightless’ economies, as pointed out by Quah (2000).

4.2.2 Why are some IT contributions high and other low ?

As mentioned above, 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 IT capital into these three components helps achieve a fuller understanding of the modes of introduction of information technologies in Europe.

The key finding from this exercise – portrayed in **Figure 1** - is that differences in accumulation rates have generally swamped differences in rates of return and capital-output ratios.

In **Figure 1**, where IT investment rates and growth contributions are contrasted, countries roughly line up along an upward trending line. Whenever information technologies made a small contribution to growth, this was seemingly due to the low amount of resources accumulated to this purpose. When IT did instead deliver a large growth dividend, this was in correspondence of buoyant IT investment, rapid fall in IT prices and high growth rates of capital stocks. This signals no major evidence of either wasted or prodigiously productive IT 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% in nominal terms and 5.9% in real terms, after taking out GDP deflator inflation. This is a relatively high real rate of return within the sample (see **Table A.3**). Comparing Ireland with Finland and Sweden precisely conveys the importance of rate of return differentials.

Finland invested the same fraction of GDP in IT capital goods as Ireland. It also started from similarly poor IT capital endowment in the early 1990s. But Finland obtained a clearly smaller growth contribution from IT than Ireland - 0.45 rather than 0.64 percentage points per year. This has (also) to do with its smaller real rate of return (4.4%), as well as with its much lower growth rates of IT capital stocks (see **Table A.2**).

The importance of rates of return also shows up when comparing Ireland with Sweden. Sweden started from a potentially advantageous position in the early 1990s, spent and invested more resources in IT than any other country in Europe (including Ireland), but faced a lower real rate of return on investment. This is partly behind the comparatively low growth contribution computed for Sweden.[21]

At the same time, the examples of Italy, Spain and Greece remind us that rates of returns are not a major determinant of the capital contributions to growth. All of these countries enjoyed the same (5.9%) real rate of return as Ireland, but their growth contributions were between one third and one half as much as the IT contribution computed for Ireland. This is essentially caused by much smaller IT accumulation rates and initially poor endowment, as shown in **Table A1**, **A2** and **A3**.[22]

4.2.3 Is the EU-US growth gap an information technology gap ?

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 I evaluate this claim in a cross-sectional dimension and in a narrower sense than in the US literature. I ask whether the growth gap suffered from EU countries *vs.* the US can be related to the gap in the accumulation of IT capital documented in the previous sections. Absent IT production data, I cannot fully evaluate the 'information technology and growth' story behind US and EU data, and thus I exclusively concentrate on its 'capital deepening' part. My calculations suggest that the fraction of growth gaps explained by IT capital is clearly non-zero, though highly varying across countries.

Table 5 provides the complete decomposition of GDP growth rates in their labour, capital and TFP components. Figures in column [1] and [2] in **Table 5** suffice to evaluate how far IT capital accumulation can go in explaining cross-country growth gaps. The shares of the overall growth gaps explained by IT capital is about 25-30% of the total for six EU countries (France, Germany, Italy, the UK, Sweden and Belgium). This fraction is much larger for Denmark (90%), and Greece, Spain,

[21] Note however that signs of a reversal of these trends are present. 1998-99 data show that there may no longer be a Swedish productivity paradox.

Portugal, the Netherlands, Austria and Finland (about 50-60%). These numbers imply that cross-sectional growth gaps in the 1990s are *also* information technology stories.

This invites the question of which factors of production, other than IT capital, mattered for growth in the EU countries. In **Table 5** (column [3]-[5]), the contributions to GDP growth of other factors of production than IT capital is provided. While deriving a summary story for the variety of patterns envisaged in **Table 5** is hard, three general remarks can be made.

(1) *Labour.* The bulk of the growth gap suffered by Italy, Germany, France and Sweden with respect to the US is explained by gaps in the contributions of labour. The growth contribution of labour was simply negative in many EU countries in the 1990s, reflecting well-documented tendencies[23], as well similar past episodes. [24] In the second half of the 1990s, though, the contribution of labour has turned positive in most countries.

(2) *Capital.* Differences in the overall contributions of capital do not explain much of the EU growth gap with the US. Typically, the growth gap attributable to IT capital is actually larger than the growth gap due to overall capital. This signals the presence of a partial 'crowding-out' effect of IT capital with respect to non-IT capital.

(3) *TFP growth.* Many EU countries exhibit higher TFP growth rates than the US. While the residual nature of TFP growth makes it particularly hard to interpret this piece of cross-sectional evidence, differences in TFP growth are seemingly crucial to make sense of the bulk of the outstanding Irish performance. Considering the time variation of the TFP growth rates throughout the 1990s with respect to the 1980s is instructive. Column [4] in **Table 6** shows that all of the five largest countries in Europe experienced smaller TFP growth in 1996-99 than in the 1980s and the first part of the decade. Instead, TFP growth accelerated in Ireland, Finland, Greece and Portugal. This closely parallels the within-Europe discrepancies in IT diffusion emphasised above. Bassanini, Scarpetta and Visco (2000) noted, though, that the acceleration of TFP growth was faster in countries with flexible labour markets and

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[22] It should be kept in mind, though, that IT capital accumulation in these countries may be under-estimated, for WITSA does not record the IT investments carried out by unincorporated enterprises.

[23] Employment creation was comparatively low and the length of the working week was shortened fast in most EU countries. In addition to that, the value added labour shares fell substantially in many European countries in the 1980s and the 1990s, as documented by Blanchard (1997).

[24] In their growth accounting study of the G-7, Dougherty and Jorgenson (1996, Table 2, p.26) found that the contribution of labour to growth was negative already in France, Germany, the UK and Italy over the period 1960-89 as well. If anything, the contribution of labour became less negative in the 1990s than in the past.

less regulated product markets. Yet this conflicts with the decline in TFP growth undergone by Spain, the UK and the Netherlands - three of the most market-friendly EU countries since the mid 1980s.

4.2.4 Summing up on IT contributions to growth

The EU as a whole has benefited from IT to a lesser extent than the US. The differences in IT spending and investment rates documented in Section 2 usually have a close correspondence in the computed growth contributions from information technologies in Europe and the United States. Ireland is the only exception, also due to its comparatively high rate of return on investment.

Hardware is the bulk of the IT story in Europe too, but European countries also appear to systematically differ in the relative contributions of telecommunications and software. Lower IT diffusion is associated to a more important role for communications equipment and a less important role for software.

Finally, overall growth gaps can be, to a non-negligible extent, associated to gaps in IT adoption and contributions.

5. Related literature

Cross-country empirical studies on the relation between information technologies and growth in Europe are scant. Schreyer (2000) first employed WITSA data to document the growth contribution of hardware and communication equipment for the G-7 in 1990-96. Van der Wiel (2000) and Oulton (2001) present with other growth accounting exercises on specific countries (the Netherlands and the UK, respectively), employing data originating from national sources.

This paper complements these earlier studies by considering a broader set of countries and years, with the further addition of software to the list of IT capital goods. In spite of the roughly similar methodology of analysis, a variety of implementation differences (concerning average services lives of capital goods, depreciation rules, as well as raw investment data) are large enough to produce different results across studies. Yet no evidence of systematic overstatement or understatement of the productivity effects of information technologies arises.

Overall, while the quoted previous papers all provide valuable and accurate pieces of information, the goal of this paper really goes beyond computation and serves the purpose of providing an overall evaluation of how far the depth of adoption of information technologies has gone in Europe – something not done before in a cross-country framework.

As mentioned above, due to the unavailability of production data, the relation between IT and growth is analysed here by looking at IT capital only. Capital deepening does not obviously subsume the entire contribution of information technologies to growth, though. A number of US studies, effectively surveyed in Brinjolfsson and Hitt (2000) and Bosworth and Triplett (2000), has sought for excess returns to IT investments within aggregate, sector and firm-level data sets, obtaining conflicting results. Lichtenberg (1995) and Brinjolfsson and Hitt (1995) found evidence of excess returns on IT investment, Berndt and Morrison (1993) didn't. These important empirical exercises are rare in Europe. Drawing on aggregate IT production data reported in the REED Electronics Yearbook, Roeger (2001) presents some evidence that the TFP contribution from IT production makes an important difference for Ireland only. Finally, using data from a large sample of some 300.000 non-financial firms, Crépon and Heckel (2000) found that the contribution of computers to growth in France was close to about 0.3 percentage points per year in 1987-98. This figure comes very close to the one found for France in this paper and is much higher than the figure computed by Cette, Kokoglu and Mairesse (2000) using national accounting data for France.

6. Conclusions

The evidence collected in this paper suggests that, in the 1990s, the European Union as a whole lagged significantly behind the United States in adopting and taking advantage of information technologies. Spending and investment rates and the growth contributions from these technologies are still usually much smaller in Europe than in the US at the end of the decade. Data for the 1990s also suggest that bridging these gaps takes time.

Yet available evidence also points to relevant asymmetries within Europe. Such asymmetries are as large as, or even larger than, EU-US differences. While available aggregate IT data are sketchy and presumably measured with error, the order of magnitude of the differences between the UK, the Netherlands, Ireland and Sweden, on the one hand, and Italy, Spain and Greece, on the other, is substantial. Germany and France, too, appear to lag behind compared to countries in Northern Europe.

The mere presence of countries on the right track towards a successful adoption of information technologies within the Union has a strong implication for the group of countries lagging behind. It should be taken to imply: it can be done. Future research cannot but address the questions: how (can it be done) ? What institutional environment is more conducive to IT adoption ? Should policy play an active role, and which role ? Answering these important questions implies a better understanding of the determinants of successful technology adoption, both at the aggregate and the micro level. The study by Gruber and Verboven (2001) on the technological and institutional determinants of the diffusion of mobile telecommunications services in the EU is a first step in the right direction.

In addition to that, much of the evidence in this paper is suggestive that at least a fraction of the cross-sectional growth gaps (between the US and the EU, within the EU), can be 'explained' by existing differences in the use and adoption of new technologies. Whether it is the successful adoption of new technologies to bring about growth, or IT capital accumulation to come about as a result of high growth rates, is not well understood yet. Most observers, politicians and businessmen are inclined to think of information technologies as 'coming first'. Yet this is far from proved. The causality issue between information technology and growth is another important question that forthcoming structural research will have to address.

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Table 1
The IT world market and the world GDP

	GDP		IT spending	
	1992	**1999**	**1992**	**1999**
EU	7.124 (30.1%)	8.491 (25.4%)	0.419 (32.2%)	0.513 (24.4%)
USA	6.319 (26.7%)	9.256 (27.7%)	0.473 (36.4%)	0.796 (38.1%)
World	23.684 (100.0%)	33.363 (100.0%)	1.301 (100.0%)	2.105 (100.0%)

Notes: Data in trillions of current US dollars. The world GDP is computed replacing the US GDP reported by the World Bank by the US GDP revised by the BEA.
Sources: World Bank WDI, BEA, WITSA (2000)

Table 2
Spending in information technologies

	[1]	[2]	[3]	[4]
	1992-99	1992	1999	[2] – [1]
Austria	4.75	4.97	4.67	-0.30
Belgium	5.58	5.45	5.80	+0.35
Denmark	6.51	6.37	6.82	+0.45
Finland	5.55	4.72	5.91	+1.19
France	5.81	5.81	5.65	-0.16
Germany	5.22	5.40	5.14	-0.26
Greece	3.77	2.38	5.30	+2.92
Ireland	5.87	5.52	6.33	+0.81
Italy	4.15	3.68	4.70	+1.01
Netherlands	6.74	6.65	7.16	+0.50
Portugal	4.39	2.78	5.04	+2.27
Spain	3.90	3.95	3.89	-0.06
Sweden	8.20	7.61	9.57	+1.96
UK	8.02	7.21	9.18	+1.97
EU	**5.66**	**5.39**	**6.04**	**+0.65**
USA	**8.03**	**7.49**	**8.63**	**+1.14**

Notes: Nominal shares of GDP. Percentage points. 'Belgium' also includes Luxembourg.
Source: BEA for the US data; WITSA (2000) for EU countries

Table 3
Investment in information technologies and total investment

	[1]	[2]	[3]	[4]	[5]	[6]
	IT investment / GDP			Total fixed investment/GDP		
	1992	1999	[2] – [1]	1992	1999	[5] – [4]
Austria	1.61	1.89	0.28	23.50	23.65	+0.15
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
Finland	1.61	2.48	0.87	19.61	19.28	-0.32
France	1.70	2.05	0.35	20.93	18.86	-2.07
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
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
Portugal	0.96	1.81	0.85	25.01	27.48	+2.46
Spain	1.52	1.58	0.06	23.09	23.69	+0.60
Sweden	2.49	3.64	1.15	18.26	16.47	-1.79
UK	2.43	3.76	1.33	16.53	17.97	+1.44
EU	1.81	2.42	0.61	20.72	21.26	+0.54
USA	2.60	4.54	1.94	17.01	20.33	+3.32

Notes: Nominal shares of GDP. Percentage points. 'Belgium' also includes Luxembourg data.
Sources: Bureau of Economic Analysis for US data. My calculations from WITSA (2000) for EU countries

Table 4

The growth contributions of IT capital and its components

	[1]	[2]	[3]	[4]	[5]	[6]
	1991-99	1991-95	1996-99	1991-99	1991-99	1991-99
	IT	IT	IT	HW	SW	TLC
USA	0.94	0.53	1.45	0.50	0.36	0.08
Ireland	0.64	0.38	0.96	0.30	0.12	0.22
Denmark	0.52	0.42	0.65	0.29	0.14	0.09
Netherlands	0.68	0.65	0.72	0.33	0.22	0.13
UK	0.76	0.43	1.17	0.39	0.26	0.11
Portugal	0.43	0.39	0.49	0.18	0.05	0.19
Austria	0.45	0.47	0.43	0.23	0.12	0.11
Spain	0.36	0.38	0.34	0.17	0.06	0.14
Greece	0.34	0.25	0.46	0.12	0.04	0.18
Finland	0.45	0.21	0.74	0.27	0.10	0.08
Belgium	0.48	0.48	0.49	0.23	0.14	0.11
Sweden	0.59	0.38	0.85	0.38	0.13	0.08
Germany(*)	0.49	0.54	0.45	0.24	0.12	0.13
France	0.41	0.40	0.44	0.20	0.11	0.11
Italy	0.31	0.28	0.35	0.15	0.05	0.11

Notes: IT = HW+SW+TLC = Hardware +Software +Communications equipment. Data in percentage points.

(*) Germany = 1992-1999

Table 5

The growth contributions of IT and non-IT capital, labour and total factor productivity, 1991-99

	[1]	[2]	[3]	[4]	[5]
	GDP	**IT CAPITAL**	**NON-IT CAPITAL**	**LABOUR**	**TFP**
USA	3.34	0.94	0.42	0.90	1.08
Ireland	6.91	0.64	0.63	1.93	3.72
Denmark	2.87	0.52	0.60	0.34	1.40
Netherlands	2.83	0.68	0.31	1.09	0.75
UK	2.68	0.76	0.37	0.51	1.04
Portugal	2.47	0.43	1.05	-0.35	1.34
Austria	2.33	0.45	1.29	-0.46	1.04
Spain	2.32	0.36	1.10	0.36	0.51
Greece	2.25	0.34	0.65	0.46	0.78
Finland	2.13	0.45	-0.13	-1.05	2.86
Belgium	1.88	0.48	0.68	0.00	0.72
Sweden	1.86	0.59	0.32	-0.28	1.23
Germany(*)	1.65	0.49	0.56	-0.23	0.83
France	1.64	0.41	0.49	-0.19	0.92
Italy	1.41	0.31	0.82	-0.30	0.58

Notes Data in percentage points. Column [1] presents GDP (business sector, measured at factor cost) growth rates in 1991-99. Column [2]-[5] present the contributions of employment (hours worked), IT and non-IT capital and total factor productivity to GDP growth.

(*) 1992-1999

Table 6
TFP growth, 1980-99

	[1]	[2]	[3]	[4]
	1980-90	1991-1999	1996-99	[3]-[1]
USA	0.4	1.08	1.3	+0.9
Ireland	3.3	3.72	4.0	+0.7
Denmark	0.8	1.40	0.1	-0.7
Netherlands	1.1	0.75	0.2	-0.9
UK	2.0	1.04	0.4	-1.6
Portugal	0.9	1.34	1.9	+1.0
Austria	1.0	1.04	2.4	+1.4
Spain	1.4	0.51	-0.0	-1.4
Greece	0.0	0.78	1.8	+1.8
Finland	2.1	2.86	3.4	+1.3
Belgium	1.1	0.72	0.5	-0.6
Sweden	0.9	1.23	1.0	+0.1
Germany(*)	1.1	0.83	0.8	-0.3
France	1.5	0.92	1.0	-0.5
Italy	1.2	0.58	-0.5	-1.7

Source: Column [1]: Scarpetta, Pilat, Scarpetta, Schreyer (2000). Column [2]-[4]: my own calculations

(*) Germany = West Germany in 1980-90; United Germany = 1992-1999

Data Appendix

IT investment in1980-1991 To calculate capital stocks for all IT 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.[25] 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 IT investment were approximated by the growth rate of the GDP shares of the corresponding IT-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. 1980-1991 data for Germany refer to West Germany.

Capital stocks 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, in line with the evidence provided by Whelan (2000a) for the United States. The loss of productive efficiency is assumed to be zero in the early years of life of an IT 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'.

[25] 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.

Rates of return and value added shares The capital share of capital good *k* in value added is:

(2) $$(r+\delta_k-\dot{p}_k)\frac{P_k K}{PY}$$

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). Overall, 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.[26] Following Hall and Jorgenson (1967) and Oliner and Sichel (1994, 2000), Expression (2) 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%, 44% and 15% are imputed to hardware, software and communications equipment. In other words, IT capital depreciates much faster than the aggregate capital stock, whose depreciation rate is 7.5% per year.[27] 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, as shown below, *r* are specified in nominal terms.) Capital-output ratios obtain 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)[28], at quality-unadjusted prices - and communications equipment are thus subtracted out of aggregate capital stocks, and the 'other capital' item obtains.

Having done so, the net rate of return obtains 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,

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[26] This rental price (and the implied gross rate of return) is supposed to be high enough to compensate an asset holder for the opportunity cost of not investing elsewhere, plus the loss due to depreciation less asset price inflation.

[27] The 7.5% 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.

[28] Schreyer (1998, Box 1, p.10) surveys the studies aimed at quantifying the difference between quality-adjusted and unadjusted price indices for computers in the US, concluding that 10 percentage points is a plausible lower bound for such difference. I concur with his conclusion and accordingly compute a new real investment series for hardware, to be used to obtain the 'other capital' residual item.

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.

Table A1
IT investment: prices and quantities, 1991-99

	Communication Equipment		Hardware		Software	
	Price	Quantity	Price	Quantity	Price	Quantity
Austria	-0.5	1.5	-15.6	23.6	-0.6	11.2
Belgium	-0.5	5.1	-15.6	23.4	-0.6	7.4
Denmark	-0.5	5.8	-15.6	23.0	-0.6	12.0
Finland	2.3	5.0	-13.2	22.6	2.2	10.6
France	-0.5	3.8	-15.6	20.4	-0.6	10.1
Germany	-0.5	1.6	-15.6	22.8	-0.6	10.6
Greece	5.6	15.8	-10.4	33.4	5.5	14.6
Ireland	0.3	13.2	-14.9	28.6	0.2	14.5
Italy	2.8	5.7	-12.8	20.1	2.7	0.9
Netherlands	-0.5	4.5	-15.6	25.1	-0.6	12.7
Portugal	1.2	15.9	-14.1	31.4	1.1	7.9
Spain	2.9	2.1	-12.7	19.3	2.8	4.9
Sweden	1.9	-0.1	-13.6	22.2	1.8	9.9
UK	-0.8	6.0	-15.9	27.2	-0.9	12.8
USA	-1.8	10.0	-18.5	38.3	-1.9	18.0

Notes: Compounded rates of change. Percentage points.
Source: BEA for US data (NIPA, Table 7.6 "Chain-type quantity and price indexes for private fixed investment by type"); my calculations from WITSA data for EU countries.

Table A2

Growth of IT and aggregate capital stocks, 1991-99

	Communications equipment	Hardware	Software	All capital goods (business sector)
Austria	9.7	29.9	12.4	4.3
Belgium	10.3	27.9	8.4	3.0
Denmark	9.8	26.6	11.7	2.9
Finland	8.8	23.8	9.7	0.5
France	11.4	24.0	10.3	2.3
Germany	13.5	29.6	13.3	2.6
Greece	16.4	42.6	16.1	2.7
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
Portugal	24.6	43.2	11.1	4.5
Spain	12.6	25.2	7.2	4.0
Sweden	5.2	25.0	9.6	2.1
UK	7.8	31.6	14.3	2.9
USA	4.9	31.2	17.4	2.6

Notes: Compounded rates of change, percentage points.
Source: my calculations from WITSA, BEA and OECD Economic Outlook 2000/1

Table A3: IT capital-output ratios, value added shares, nominal and real gross and net returns

	Capital-output ratios (1999)				**Income shares (1999)**				**Gross rates of return (1991-99)**			**Nominal 1991-99**	**Real 1991-99**
	TLC	Hardware	Software	**IT**	TLC	Hardware	Software	**IT**	TLC	Hardware	Software	**r**	**r**
Austria	0.049	0.022	0.024	**0.095**	0.008	0.011	0.011	**0.030**	0.243	0.460	0.533	**0.069**	**0.044**
Belgium	0.053	0.024	0.038	**0.115**	0.008	0.012	0.017	**0.037**	0.225	0.442	0.518	**0.050**	**0.029**
Denmark	0.057	0.032	0.034	**0.124**	0.008	0.016	0.015	**0.039**	0.196	0.413	0.487	**0.021**	**0.001**
Finland	0.054	0.032	0.028	**0.115**	0.010	0.017	0.014	**0.041**	0.213	0.435	0.506	**0.063**	**0.044**
France	0.052	0.020	0.028	**0.100**	0.009	0.010	0.013	**0.032**	0.229	0.445	0.520	**0.056**	**0.040**
Germany	0.055	0.022	0.028	**0.105**	0.008	0.011	0.013	**0.032**	0.237	0.454	0.527	**0.064**	**0.043**
Greece	0.070	0.011	0.007	**0.088**	0.014	0.006	0.004	**0.024**	0.248	0.483	0.539	**0.153**	**0.050**
Ireland	0.081	0.026	0.017	**0.124**	0.023	0.016	0.010	**0.049**	0.257	0.466	0.550	**0.085**	**0.059**
Italy	0.056	0.016	0.018	**0.089**	0.013	0.009	0.009	**0.031**	0.238	0.456	0.532	**0.098**	**0.059**
Netherlands	0.064	0.031	0.044	**0.139**	0.011	0.016	0.020	**0.047**	0.238	0.456	0.527	**0.063**	**0.044**
Portugal	0.069	0.018	0.011	**0.097**	0.009	0.009	0.005	**0.023**	0.213	0.446	0.515	**0.074**	**0.013**
Spain	0.056	0.016	0.015	**0.087**	0.011	0.009	0.007	**0.027**	0.246	0.467	0.544	**0.103**	**0.060**
Sweden	0.073	0.046	0.038	**0.158**	0.013	0.024	0.018	**0.055**	0.205	0.426	0.497	**0.059**	**0.034**
UK	0.074	0.041	0.052	**0.166**	0.015	0.022	0.026	**0.063**	0.200	0.424	0.496	**0.038**	**0.007**
USA	0.071	0.048	0.064	**0.182**	0.016	0.029	0.034	**0.079**	0.233	0.464	0.527	**0.068**	**0.046**

Figure 1
IT investment and contribution of IT capital to growth
US and Europe, 1991-99