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SEARCHING FOR THE DETERMINANTS OF IT INVESTMENT

PANEL DATA EVIDENCE ON EUROPEAN COUNTRIES

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Abstract

The aim of this paper is to identify the degree of information technology (IT) adoption in individual European economies and to analyse the determinants of IT investment among a panel of EU countries. We first analyse the dynamics of IT investment expenditure in 15 European countries from 1992 until 2001 and, by means of a cluster analysis, we draw a picture of IT diffusion in Europe. By clustering the European countries according to their shares of IT spending over GDP, we identify three fairly stable groups of fast, medium and slow adopters. We then build an econometric equation of the determinants of IT investment to use with panel data in estimations for five European economies over the period of 1980 to 2001. We consider aggregate IT investment as well as separate investment in hardware or software. Financial conditions, income growth and comparative advantage turn out to affect IT investment, but we find that the determinants of hardware investment only partially overlap with those of software.

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1. Introduction

During the late 1990s, information technology (IT) accounted for a large and growing share of investment and contributed significantly to output growth, particularly in the United States. The diffusion of IT throughout the economy has improved economic efficiency and substantially increased productivity growth in the US as well as in other OECD countries. Because of the impressive productivity performance of the US economy in the late 1990s, most of the recent research has been devoted to analysing the impact of IT (or ICT, which also includes communication technologies) production and diffusion on US productivity growth (Oliner & Sichel, 2000; Jorgenson & Stiroh, 2000). The main message from these studies is that the US economy can be viewed in many respects as a technology and productivity 'leader'. If a new IT-based source of productivity growth is established in the US economy, this raises the potential for other countries to follow suit.

During the same period, IT investment has considerably increased in European countries as well, but this has not always been followed by an equivalent acceleration in productivity growth. Moreover, the contribution of information technology to growth seems to be quite diverse across European countries (van Ark et al., 2002). Thus, it is crucial to investigate the record of European countries in adopting new technologies and reducing their IT gap *vis-à-vis* the US.

The aim of this paper is first to identify the stage of IT adoption in individual European economies and then to analyse the determinants of IT investment in a panel of 'representative' EU countries. A brief review of the literature on IT diffusion and investment is presented in section 2, which is based on both comparative and individual country studies. In section 3, we study the dynamics of IT investment expenditure in 15 European countries from 1992 to 2001 and, by means of a cluster analysis, we draw a picture of IT diffusion in Europe. By clustering the European countries according to their GDP shares of IT spending, we identify three fairly stable groups during the 1990s: fast, medium and slow adopters. In section 4, we build an econometric equation of IT investment to use in estimations with panel data on European economies over the period of 1980 to 2001, considering both aggregate IT investment and disaggregating between hardware and software. Since most European countries have only recently started to collect data on investment in IT items (and for several countries these data are still unpublished), we choose one or two representative countries for each of the three groups previously mentioned and perform the econometric analysis for these countries. Section 5 discusses our econometric findings on the determinants of IT investment in Europe. Final remarks and suggestions for further research are discussed in section 6.

2. ICT diffusion and investment: A brief review

Since the mid-1990s, almost a decade after the start of the 'endogenous growth' debate, the so-called 'New Economy' and its relationship with growth has moved to the centre-stage. More and more researchers have begun to study the conceptual links between the introduction of ICT and economic growth, and evaluate their quantitative effects on national accounts. One reason for this widespread interest has been the mounting attention to the 'computer productivity paradox', i.e. why productivity growth in the US was not so strong in the 1980s and early 1990s, despite the spread of ICT throughout the economy (Triplett, 1999).

A number of interpretations have been provided for this paradox. First, there was (and possibly is) a measurement problem involved in the definition of the ICT sector itself, and then in the economic evaluation of the ICT goods. The problem is now apparently solved as the OECD provides an official definition of ICT; thus ICT goods and services are evaluated taking account of their inner quality (in the US, with the tool of hedonic pricing; see Colecchia & Schreyer, 2001, for an overview of such methodological issues).

Another interpretation draws on the definition of 'productivity' and on the productivity dynamics postulated by New-Economy theorists. The distinction between the production and use of ICT is central in this case. According to a simple two-sector neoclassical framework, if we are to measure the growth contribution of technical progress in the sectors *producing ICT*, we have to compute *total factor productivity* in the ICT-producing industries, as in this case technical progress is associated with an outward shift of the production function. If alternatively we are to measure the impact of *ICT utilisation* on the productivity of the whole economy, we have to calculate the variation in *average labour productivity* associated with the economy-wide rise in ICT investment (see Stiroh, 2001a). This distinction is fundamental, because the overall impact of ICT on per capita output crucially depends on which is the main channel of productivity improvement and on the relative weight of the ICT sector *vis-à-vis* the rest of the economy. On the one hand, the contribution of technical progress is the smaller of these factors, so the relative weight of the ICT-producing sector is lower. On the other hand, in order for the effects of the ICT investment channel to become visible, more time is required for the new capital goods to fully generate a strong and permanent effect on labour productivity. Both these features may contribute to explaining the computer productivity paradox.

A third interpretation has to do with productivity spillovers associated with ICT adoption. In this case as well, one can distinguish between spillovers owing to the diffusion of technical progress from the *ICT-producing* sectors, and productivity spillovers owing to the *use of ICT* in the rest of the economy (such as network externalities or technical complementarities with innovations being generated in other sectors, as in the aircraft industry). Moreover, productivity improvements stemming from the production or the utilisation of ICT could reinforce each other, for instance through intense producer-customer relationships prompted by proximity (see Rosenberg, 1982). Here again, the measurement issue and the identification of the spillovers may partially explain the paradox mentioned before.

Empirical studies on the contribution of ICT to growth have flourished in the US in recent years and the debate has eventually moved from a US-centred to an international dimension. In May 1999, the Economics Department of the OECD launched an ambitious two-year research project on Sustainable Growth and the New Economy, which has so far provided us with a great deal of comparative studies on the nature and dynamics of innovation- and information-based growth. The starting point of these comparative studies is twofold. First, there is still evidence of a gap in the relevance of the ICT sector between continental Europe, on the one side, and the US and a few other industrial countries on the other side (see for instance OECD, 2003). Second, the growth performance of continental Europe and Japan has been worse than that of the US in the second half of the 1990s, although the ICT investment gap has been progressively closed during the decade (Schreyer, 2000).

Even within Europe, laggards (Italy, Spain and to a lesser extent Germany and France) and fast adopters (the UK, the Netherlands, Sweden and Finland) can be identified (van Ark et al., 2002). Nevertheless, once industrial economies are classified according to their ICT endowments, the question becomes whether the wedge between fast and slow adopters has been partially closed since the mid-1990s. For some ICT components, the answer seems to be positive. According to Colecchia & Schreyer (2001) the annual rate of growth of IT investment at constant prices during 1995–2000, based on harmonised indexes, has been 32.4% in the US, 31.6% in France, 31.2% and 30.9% respectively in Italy and Germany. As a matter of fact, ICT expenditure rates are now close to 6% of GDP in Western Europe, with a strong catch-up effect *vis-à-vis* the US (Iammarino et al., 2001).

This point brings us to the second topic mentioned in the Introduction. The US experienced a historically unprecedented period of growth during the 1990s, while the pace of economic growth has been (and is) sensibly slower in continental Europe. Of course, many factors contributed to these outcomes, including fiscal consolidation in Euroland, accommodative monetary policy in the US, structural differences in labour, product and financial markets across the Atlantic, and the higher weight of R&D in the US economy relative to Europe. Yet the estimated growth contribution of information technologies was substantial in the UK and the Netherlands, and rapidly increased during the 1990s in Finland, Ireland and Denmark. Conversely, new technologies contributed less to growth in France, Germany, Belgium and Sweden, and only marginally in Spain and Italy (van Ark et al., 2002). Hence, with the notable exception of Sweden, the distinction between fast and slow IT adopters in Europe replicates that between economies with a high or a low contribution of IT to aggregate growth. Therefore, it is crucial to investigate more deeply the dynamics of IT adoption in EU countries, and the determinants of IT investment both at the micro- and at the macroeconomic level (for the Italian case, see for instance the essays in Rossi, 2002).

Another intriguing issue is to what extent the US success story is accounted for by the existence of a strong IT-*producing* sector, which is lacking in several countries in Europe.[1] In other words, is there a key issue of comparative advantage in high-tech industries that is consistent with a windfall of technical progress in the US but *not* in continental Europe? Roeger (2001) suggests that productivity growth is associated with the comparative advantage the US has in the production of high-tech goods, hence comparative disadvantage and not just Euro-sclerosis must be blamed for the inferior growth performance of the EU. Moreover, comparative advantage in *producing* IT could also be associated with faster-than-average *adoption* of IT in the economy, owing to manufacturer-customer relationships that are favoured by proximity and a common language.

Country studies of European economies have been mainly devoted to quantifying the contribution of new technologies to economic growth by means of a growth-accounting approach. Further, because of the complexity of official estimates of ICT capital-formation (Iammarino et al., 2001), and to the paucity of data, country studies have been mainly devoted to the measurement of ICT investment and to the analysis of the impact of new technologies on productivity growth, and less to the determinants of IT investment. Among them, Oulton

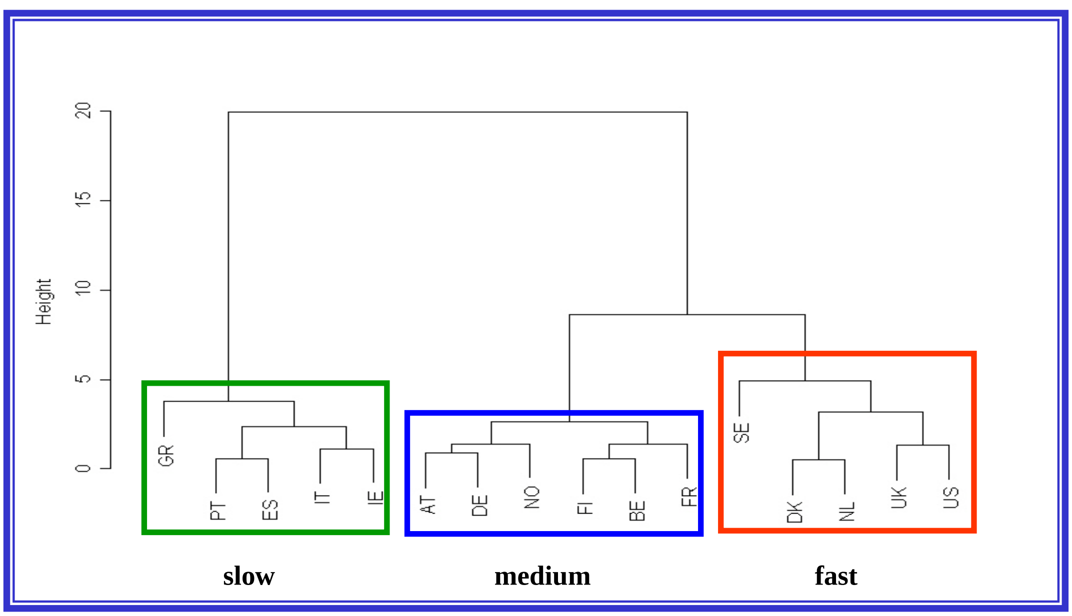
[1] See Gordon (2003) among others.

(2001) develops new estimates of the investment in and output of information and communication technologies for the UK and measures the contribution of ICT to the growth of output and productivity for the period 1980–99. Melka et al. (2003) follow a similar approach to assessing the role of ICT in stimulating the French economy: their main purpose is to make a first step towards a thorough identification of the sources of growth across industries, in order to comprehend more properly the contribution of new technologies to overall productivity in ICT-using and ICT-producing industries in France.

3. IT diffusion among European countries: A cluster analysis

In this section we draw a picture of the diffusion of IT investment expenditure across Europe over the period 1992–2001. We focus on information technologies that exclude communication equipment because the latter includes a large share of rather 'traditional' investment goods, whose behaviour in terms of investment functions and contribution to productivity growth is likely to be different than for IT.[2] In particular, we track the variability of the expenditure share of IT over GDP across 15 European countries plus the US. To study the variability of the IT/GDP ratio across countries and across time, we employ the Ward method to the analysis of variance that allows us to evaluate the distance between clusters of countries (Everitt et al., 2001). This method minimizes the sum of squares of any two (hypothetical) clusters that can be formed at each step of the analysis, and therefore is consistent with a minimum-variance approach. We applied Ward's methodology both to the data for the whole period of 1992 to 2001 and year-by-year data. Figure 1 displays the results we obtain when implementing Ward's algorithm on data for the entire period: three groups of countries (slow, medium and fast IT-adopters) are identified. Among the fast adopters, Sweden is associated with the highest IT/GDP ratio, while among the slow adopters Greece displays the lowest IT/GDP rate.

Figure 1. Clustering of the countries based on IT/GDP: 1992–2001

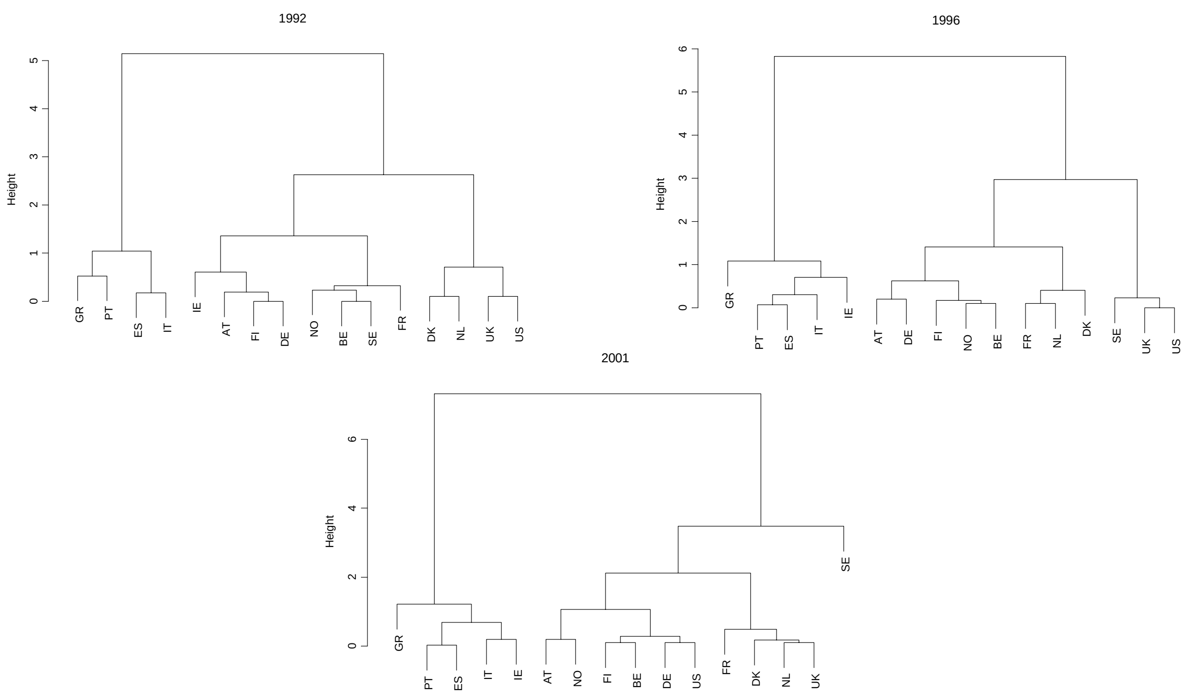


[2] See the Appendix for a definition of the IT and CT sectors, which draws on the economic activity classification (ATECO 91) that follows the NACE rev.1 up to the fourth digit level. The fifth level that is used in the present analysis is a further disaggregation of the fourth.

The three emerging groups are basically consistent with those identified in the literature (see for instance OECD, 2003, chapter 1): the US, the UK plus some Scandinavian countries and the Netherlands are fast adopters; continental Europe plus other Scandinavian economies are medium adopters; and Mediterranean countries plus Ireland are slow adopters. The main difference between this and other studies concerns France, which ranks higher here than in other classifications, and also Finland, for which the opposite is true; note, however, that our clusters are based on IT data that exclude communication equipment and services, which may explain why France performs better (and Finland performs worse) in our classification than in others.

Figure 2 shows the results we obtain year by year. It is interesting to note that during the whole period only a few countries moved across groups. In particular, with the exception of Ireland (which was classified as a medium adopter in 1992 and as a slow adopter in the following benchmark years), slow adopters and most of the medium adopters (Austria, Finland, Belgium and Norway) maintained their original ranking over time. Meanwhile, rankings among fast adopters shifted almost every year, although only Sweden moved from the medium into the fast-adopters' cluster over time. The next step is to search for the common determinants of IT investment across European economies and to identify key relationships that may account for the persistent differences they display in the rate of IT adoption (as proxied by the ratio of IT investment to GDP).

Figure 2. Cluster analysis: dynamics



4. The determinants of IT investment in European countries: Empirical model and data

In order to move from the description of national patterns of IT accumulation to the analysis of the determinants of IT investment across European countries, we build an econometric model to be estimated with panel data for five representative EU countries during 1980–2001, where 'representative' refers to the fact that at least one country for each of the three clusters identified above is included in the sample. The model we adopt is rather eclectic in that it combines features of standard models of aggregate investment with features we believe can usefully be applied to the specific case of IT investment choices.[3]

According to the Keynesian tradition, aggregate investment is modelled as a function of disposable income and the real interest rate; disposable income is in turn related to gross domestic product (see for instance Pindyck & Rubinfeld, 1981, chapter 14). In our case, we estimate the *share* of IT investment over GDP and we normalise other variables with gross domestic product, hence we do not include disposable income among the explanatory variables. Nevertheless, we do include a proxy for the (expectation of) growth of the size of the national market – the lagged rate of growth of GDP. To account for country-specific financial conditions we use long-term real interest rates, lagged one year, as their influence on IT investment is likely to occur after a time lag (this variable is common both to the Keynesian and to the neoclassical approach to aggregate investment: see Blanchard & Fischer, 1989, chapter 2). More recent theoretical and empirical approaches to business investment underline the key role of liquidity constraints in an environment characterised by widespread financial market imperfections. Liquidity-constrained entrepreneurs have to rely on retained profits as well as on credit flows to finance their investment plans (see for instance Fazzari et al., 1988). In this case, higher profit shares in the distribution of GDP should be associated with higher investment rates. Other scholars point to a different causal link, going from higher wage compensations to a more intense substitution of capital to labour inputs in the production function, hence to higher investment rates (see Daveri & Tabellini, 2000). As labour and profit share (where the latter includes the compensation for capital services) are linked through the accounting identity of the distribution of national income, we use either aggregate labour costs (compensation per employee – CPE) or net operating surplus (NOS) as shares of GDP. As in the case of the real interest rate, we include the lagged value of CPE/GDP or NOS/GDP, as financial conditions (or relative factor prices) are supposed to affect investment rates after a time lag.[4]

Concerning the variables that belong to standard models of aggregate business investment, we turn to variables that may apply to the specific case of IT investment choices. The literature on the determinants of ICT diffusion among national economies points to a number of variables, such as the direct costs of ICT, implementation barriers, risk and uncertainty related to the applications of new technologies, and the competitive and regulatory environment (see OECD, 2003). Unfortunately, most of these variables are barely viable in our context, either because they are conceptually flawed when analysing the EU, or because data are difficult to collect or are substantially unavailable on a yearly basis. Take for instance the price of IT goods: there should not be significant differences in such prices within the EU internal market, as in principle even non-tariff barriers such as the technical requirements for IT goods should not be so different across EU economies as to drive a price wedge. Quantifying risk

[3] See Chirinko (1993) for a survey of business investment models.

[4] We also tried different lag structures for financial and other variables, but with no appreciable results.

and uncertainty related to the applications of new technologies is very difficult, and it is almost impossible to provide time-series data on that. More information has become recently available on the competitive and regulatory environment of OECD countries (see for instance, Nicoletti et al., 2000). Drawing on this source of data, Alesina et al. (2003) estimate a dynamic model of investment in utilities, transport and telecommunication and find that net investment is significantly hampered by tight regulation. We have tried to take advantage of this literature and have included an economy-wide measure of regulatory strictness in our regressions of IT investment, but no significant effects of this variable have been detected in this context.[5]

Among other factors potentially affecting IT investment across EU economies, we have selected a (rough) measure of national comparative advantage in IT (the share of export over import of IT capital goods, EXP/IMP) and a measure of the intensity of R&D expenditure per country (R&D/GDP). *A priori*, we expect comparative advantage in the production and trade of IT goods (as measured by a high value of EXP/IMP) to positively affect IT investment, as production and utilisation of IT could reinforce each other through close producer-customer relationships prompted by proximity. National comparative advantage could also be significant as a proxy for direct costs and implementation barriers relative to the IT sectors, if the assumption of price equalisation within the borders of the EU internal market fails to hold. Furthermore, we expect the aggregate intensity of R&D expenditure to positively affect IT investment if R&D-intensive sectors or firms tend to command more IT investment (in the Italian case, there is evidence that this holds: see De Arcangelis et al., 2003). Therefore, our baseline empirical relationship is shown in Equation 1.

Equation 1

$$\left(\frac{I_{tech}}{GDP}\right)_{i,t} = \alpha_{0,i} + \alpha_1 r_{i,t-1} + \alpha_2 (d\ln GDP)_{i,t-1} + \alpha_3 \left(\frac{R\&D}{GDP}\right)_{i;t} + \alpha_4 \left(\frac{CPE\,or\,NOS}{GDP}\right)_{i,t-1} + \alpha_5 \left(\frac{EXP}{IMP}\right)_{i,t(IT)} + \varepsilon_t$$

where:

tech = IT, hardware, software;
i = GE, FR, ITA, NE, UK;
t = [1980;…; 2001]
r = 10-yrs. real interest rate;
GDP = gross domestic product;
R&D = BERD, business enterprise expenditure on R&D (or other proxies for R&D expenditure as indicated in the tables);
CPE = aggregate labour compensation in the business sector (compensation per employee);
NOS= net operating surplus in the business sector; and
(EXP/IMP) = export over import in the 'office machine and computer industry'.

We use yearly data for five countries (Germany, France, Italy, the Netherlands and the UK during 1982–2001. Each of the three diffusion clusters relative to EU countries – as identified in Section 3 – is represented in our panel. All variables (except of course the real interest rate, the export-import ratio and the growth rate) have been normalised by GDP in order to avoid dimensional effects and then log-transformed. Lack of detailed information on IT capital goods, such as prices and depreciation rates, as well as a long enough time series on IT stocks

[5] We used the OECD summary indicator of employment protection legislation, (Nicoletti et al., 2000).

for every country, implies that the normalisation to GDP is possibly the best available choice. We estimate our equation by using a least square dummy variable method (LSDV), which amounts to assuming a country-fixed effect.

Official data on ICT investment, although often partial and for a few years only, are available for most EU member countries (van Ark et al., 2002). Nevertheless, for only five countries (Germany, France, Italy, Netherlands and the United Kingdom) does the available disaggregated data series for the three main ICT investment categories (hardware, software and communication equipment) cover a long enough time interval.[6] Other countries (Austria, Finland, Ireland and Sweden) only publish data on software. We have thus assembled a time series that is sufficiently long (covering 1980–2001) for those five EU countries, in order to analyse the determinants of IT expenditure at current prices. Data have been collected on IT investment and its components in the five EU countries and on the variables to be tested as exogenous determinants of IT expenditure at the macro level. All data stem from national account sources, except for the UK whose data on IT capital goods are taken from Oulton (2001).[7]

5. Empirical findings

We first discuss the estimates of Equation 1 using data for the investment in IT as a whole and then provide separate estimates for investment in hardware and software.[8] As shown in the first column of Table 1, our empirical equation fits yearly data on IT investment in the five EU countries rather well, although when taken individually only some of the coefficients are statistically significant. The real interest rate has a negative coefficient as expected; the share of labour costs is negatively correlated with IT investment, supporting the financial constraint hypothesis against the labour-capital substitution conjecture. In order to test the financial constraint hypothesis more directly, in the second column we re-estimate the equation using NOS instead of the aggregate labour share (i.e. CPE) and find a weaker but still significant positive coefficient as expected. Although the lagged growth rate of GDP tends to show a positive relation with IT investment, R&D intensity does not display a statistically significant relationship with IT/GDP. Our measure of comparative advantage is instead positively and significantly correlated with the endogenous variable. In the third column we experiment with an alternative measure of R&D, but the results are not consistent with our *a priori*.

If IT capital is complementary to skilled labour or to the share of scientists or technicians in the labour force, it may be the case that IT investment raises with the national level of higher education or with the proportion of the labour force that has scientific or technical skills. We have controlled for a wide range of these variables in the regressions, but obtained no significant result. Once again, this is possibly because of the patchiness of our proxies, hence more research needs to be undertaken in the direction of testing more refined measures of the skills required by IT investment.

[6] IT data for the UK are available only until 1998. The data for 1999–2001 are estimates by the authors.

[7] Italian data are from ISTAT – National Accounts; data for Germany, France and Netherlands come from the European Central Bank; while the source of the UK data is Oulton (2001).

[8] See the Appendix for a detailed definition of IT capital goods.

Table 1. Estimation results: IT

	LSDV		
Variable	1	2	3
(Int. Rate)	-0.046 (0.013)	**-0.036** (0.014)	-0.043 (0.013)
(CPE)/(GDP)	-1.751 (0.363)	-	-1.292 (0.401)
(NOS/GDP)	-	*0.496* (0.249)	-
(dlnGDP)	*0.006* (0.003)	0.005 (0.004)	**0.008** (0.004)
(R&D)/(GDP)	-0.115 (0.156)	0.022 (0.181)	**-0.025*** (0.011)
(EXP)/(IMP)	0.393 (0.147)	0.772 (0.174)	0.478 (0.150)
Adj. R sq.	0.882	0.848	0.876
SSE	0.119	0.134	0.120
n. obs	74	74	74
d. of freedom	64	64	64

Notes: LSDV = least squares dummy variable; standard errors are in parentheses; underlined means significative at 1%; and boldface means significative at 5%, italics at 10%.

* In this case, the R&D indicator is the percentage of BERD conducted by the business enterprise sector and implemented in the 'office machine and computer industry' only. The normalisation by GDP does not of course apply in this case.

One possible reason why some of the variables included in Equation 1 turn out not to be statistically significant is that they affect hardware and software investment in a different way; merging together the data on hardware and software may then be inappropriate. Table 2 on the determinants of investment in hardware supports this conjecture. The first column shows that all the variables included in Equation 1 turn out to be significant in explaining hardware investment, with the expected results. More precisely, financial tightness has a negative impact, while growing domestic demand, a higher intensity of R&D and comparative advantage in the hardware sector enhance the accumulation of hardware. In the second column, instead of CPE we have used NOS, which is associated with a positive but an insignificant coefficient, while no remarkable differences arise for the other variables. In the third column we test an alternative proxy for R&D, which yields results comparable with those in the first column. Finally, in the fourth column we check for complementarity between hardware and software, including lagged investment in software among the determinants of hardware investment. The data, however, do not support the hypothesis that more investment in software command more investment in hardware the year after.[9]

[9] We also have tried different lag structures, but the results were not encouraging. Further, education and skill variables did not turn out to be significant for hardware investment either.

Table 2. Estimation results: hardware

	LSDV			
Variable	1	2	3	4
(Int. Rate)	-0.044 (0.012)	-0.040 (0.013)	-0.041 (0.013)	-0.041 (0.012)
(CPE)/(GDP)	**-0.855** (0.357)	-	**-0.736** (0.368)	-0.631 (0.390)
(NOS/GDP)	-	0.247 (0.224)	-	-
(dlnGDP)	0.013 (0.004)	0.012 (0.004)	0.013 (0.003)	0.014 (0.004)
(R&D)/(GDP)	**0.339** (0.153)	**0.407** (0.163)	**0.012*** (0.006)	**0.414** (0.162)
(EXP)/(IMP)	0.426 (0.144)	0.613 (0.157)	0.423 (0.145)	0.391 (0.146)
$SW_{(T-1)}$	-	-	-	0.095 (0.069)
Adj. R sq.	0.902	0.895	0.901	0.903
SSE	0.117	0.121	0.118	0.116
n. obs	74	74	74	74
d. of freedom	64	64	64	64

Notes: LSDV = least squares dummy variable; standard errors are in parentheses; underlined means significative at 1%; and boldface means significative at 5%, italics at 10%.

* In this case, the R&D indicator is the percentage of GERD (general expenditure on R&D) conducted by the business enterprise sector. The normalisation by GDP does not of course apply in this case.

In the case of software investment, Table 3 shows that while the set of financial proxies behaves consistently with the assumption, this is not true of the other variables (see the first column). The proxy for the (expectation of) domestic demand dynamics is not significant; R&D intensity exerts a *negative* effect on software investment, while our proxy for comparative advantage seems to play no role in determining EU patterns of software investment. Using NOS instead of CPE makes the coefficient of EXP/IMP significant, but worsens that of the interest rate (the second column), while testing a different measure of R&D does not alter the picture (the third column). Interestingly, lagged expenditure in hardware has a positive and significant effect on software investment (the fourth column).[10]

Taken together, Tables 1-3 suggest:

- The real interest rate has a negative coefficient as expected and also the share of labour costs is negatively correlated with IT investment, pointing to a negative effect of financial tightness on IT investment. This effect is also true in the case of hardware and software investment when viewed separately.
- These results are robust once net operating surplus is included instead of labour costs (of course NOS has a positive coefficient), but only in the case of aggregate IT and software.

[10] Even for software, education and skill variables turn out to be not significant.

Table 3. Estimation results: software

	LSDV			
Variable	1	2	3	4
(Int. Rate)	**-0.049** (0.020)	-0.036 (0.022)	-0.034 (0.020)	-0.032 (0.021)
(CPE)/(GDP)	-2.109 (0.598)	-	-	-1.930 (0.583)
(NOS)/(GDP)	-	**0.963** (0.378)	0.941 (0.337	-
(dlnGDP)	-0.002 (0.006)	-0.005 (0.006)	0.003 (0.006)	-0.006 (0.005)
(R&D)/(GDP)	-0.725 (0.257)	*-0.497* (0.274)	-0.071* (0.016)	-0.923 (0.262)
(EXP)/(IMP)	0.338 (0.242)	0.907 (0.264)	0.944 (0.238)	0.140 (0.248)
$HW_{(T-1)}$	-	-	-	**0.413** (0.176)
Adj. R sq.	0.923	0.917	0.931	0.928
SSE	0.196	0.204	0.185	0.190
n. obs	74	74	74	74
d. of freedom	64	64	64	64

Notes: LSDV = least squares dummy variable; standard errors are in parentheses; underlined means significative at 1%; and boldface means significative at 5%, italics at 10%.

* In this case, the R&D indicator is the percentage of BERD conducted by the business enterprise sector, and implemented in the 'office machine and computer industry' only. The normalisation by GDP does not of course apply in this case.

- Growing domestic demand, a higher intensity of R&D and comparative advantage enhance the accumulation of hardware.
- In the case of software investment, only the set of financial proxies behaves consistently with the theoretical assumptions. R&D intensity displays a negative relationship, while the coefficients of domestic demand and comparative advantage tend to be estimated less precisely. Software investment does respond positively to lagged hardware accumulation.

An explanation for these results for software investment could be that sectors with a low R&D intensity tend to invest relatively more in software than in hardware (for instance, this could be the case for some service sectors such as business services, see for example, Tomlinson 2001). If this is the case, a rise in software investment need not be positively correlated with an increase in the share of R&D expenditure. As for comparative advantage, it is likely that producer-customer relationships prompted by proximity are more relevant for investment in hardware than in software, which could explain the poor performance of EXP/IMP as a right-hand side variable in Table 3.

6. Conclusions and hints for future research

In this paper, we first analysed the dynamics of IT investment expenditure in 15 European countries from 1992 to 2001 and, by means of a cluster analysis, we drew a picture of IT diffusion in Europe. By clustering the European countries according to their GDP shares of IT spending, we identified three fairly stable groups, labelled fast, medium and slow adopters.

We then built an econometric equation of the determinants of IT investment to be used in estimations with panel data for five European economies during the period of 1980 to 2001, considering aggregate IT investment as well as disaggregating between hardware and software.

Financial conditions, income growth and comparative advantage turn out to affect IT investment, but the determinants of hardware and software investments differ considerably. On the one hand, the real interest rate has a negative coefficient as expected and the share of labour costs is also negatively correlated with IT investment. This result is also true in the case of hardware and software investment when viewed separately. On the other hand, growing domestic demand, a higher intensity of R&D and comparative advantage enhance the accumulation of hardware, but this is not generally true for software. In the case of R&D intensity, software investment displays a negative relationship. Moreover, software investment does respond positively to lagged hardware accumulation, while the converse in not true.

A possible explanation for the peculiar results for software investment is that sectors with a low R&D intensity tend to invest relatively more in software than in hardware (for instance, this could be the case of some service sectors such as business services). If this is the case, a rise in software investment need not be positively correlated with an increase in the share of R&D expenditure. As for comparative advantage, it is likely that producer-customer relationships prompted by proximity are more relevant for investment in hardware than in software. In any case, more research is needed to investigate the specific determinants of investment in different categories of IT goods.

There are two other dimensions of the determinants of IT investment where more analysis is greatly needed: first, in the direction of obtaining more refined measures of regulatory and competition pressures that can be usefully applied to the case of IT investment; and second, in the direction of testing more refined measures of the education attainments and labour skills required by IT diffusion.

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Appendix

The ICT industry (excluding goods-related services)

Manufacturing

30010 Manufacture of office and accounting machinery
30020 Manufacture of computing machinery
31300 Manufacture of insulated wires and cable
32100 Manufacture of electronic valves and tubes and other electronic components
32201 Manufacture of television and radio transmitters
32202 Manufacture of apparatus for line telephony and line telegraphy
32203 Repairing of television and radio transmitters and apparatus for line telephony and line telegraphy
32300 Manufacture of television and radio receivers, sound or video recording or reproducing apparatus, and associated goods
33201 Manufacture of instruments and appliances for measuring
33202 Manufacture of gas water and other liquids meters for measuring, checking, testing
33203 Manufacture of navigational aids, hydrological, geophysical and meteorology instruments
33204 Manufacture of instruments and appliances for other purposes, except industrial process control equipment
33205 Repairing of scientific and precision instruments (optical ones excluded)
33300 Manufacture of industrial process control equipment

Intangible services

64200 Telecommunications
72100 Hardware consultancy
72200 Software consultancy and supply
72300 Data processing
72400 Data base activities
72500 Maintenance and repair of office, accounting and computing machinery
72601 Services of telematics, robotics, computer graphics
72602 Other computer related activities

ICT capital goods

Hardware: (30010) manufacture of office and accounting machinery and (30020) manufacture of computing machinery.

Software: (72200) Software consultancy and supply; (72300) data processing; (72400) data base activities; (72500) maintenance and repair of office, accounting and computing machinery; (72601) services of telematics, robotics, computer graphics; (72602) other computer related activities.

Communication equipment**:** (32100) manufacture of electronic valves and tubes and other electronic components; (32201) manufacture of television and radio transmitters; (32202) manufacture of apparatus for line telephony and line telegraphy; (32203) repairing of television and radio transmitters and apparatus for line telephony and line telegraphy; (32300) manufacture of television and radio receivers, sound or video recording or reproducing apparatus, and associated goods; (33201) manufacture of instruments and appliances for measuring.

IT sector: hardware and software sectors

CT sector**:** communication equipment sectors

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