Finance and the Diffusion of Digital Technologies

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The paper examines how different dimensions of financial development have influenced firms' willingness to adopt new digital technologies (IT). To do so, it introduces an econometric analysis based on an Error Correction Model run over a panel of fifteen industrialized countries. The results point to the importance of stock market development and suggest that market-based systems encourage digital investments better than bank-based ones. The evidence is consistent with theories that stress the effective selection of projects carried out by stock markets and the positive role that new financial tools traded within these markets had on IT adoption. [JEL Classification: O31, O33, G20, G24, E44, C22]

Keywords: digital technologies, financial structure, cointegration.

1. - Introduction

Misquoting Robert Solow's famous remark[1], we must observe

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* <*bruno.caprettini@gmail.com*>. I wish to remember the late Prof. Fernando Vianello. His contribution to this work is much deeper than the suggestions he gave me while I was completing the thesis, as he advised and encouraged me throughout my academic career and ultimately shaped most of my economic understanding. I am also deeply indebted to my supervisor Prof. Piercarlo Padoan, and to Prof. Massimiliano Tancioni, Matteo Luciani, Corrado Pollastri and Filippo Belloc: without their bright ideas and invaluable support this paper would have been entirely different – and definitely worse. Finally, I wish to thank the anonymous *referees* of *Rivista di Politica Economica* who red and commented the first draft of the paper: their helpful criticisms and advises were precious and improved a great deal this final version. Of course, none of the above bear any responsibility for the mistakes still in the text, which are all mine.

[1] As late as 1987, Robert Solow, commenting on American economic

that "we can see the computers everywhere, finally *also* in the productivity statistics". As a matter of fact, the impact of computers and digital technologies has become apparent at least since the mid-90s, and today nobody really doubts that these technologies have been fuelling enormous efficiency gains wherever they have been adopted[2].

Here as in the following, we will refer to *digital technology* (or *Information and Communication Technology*-ICT) meaning any device apt to capture, process, transmit and display data and information electronically; a definition which leads to consider ICT every good that falls into four broad categories: 1) *hardware* 2) *software* 3) telecommunication equipment and 4) other similar devices such as computing machines or photocopiers[3].

A major fact regarding ICTs is their ability, once they have been introduced in the economic system, to impose a new *technological paradigm*: a new set of routines, know-hows and organizational structures broadly different from the preceding ones and substantially more efficient[4].

The very nature of gains brought about by the digital revolution – the higher efficiency of production – justly place attention upon the attitude showed by firms with respect to these technologies. In fact, the question of why ICT diffusion has promoted higher productivity gains in some places rather than in others, must necessarily be addressed through the analysis of the reasons why firms in these countries have been readier to adopt these technologies. Over the last decade, a growing literature has singled out several *facilitating factors*, that is a set of social and economic conditions crucial for digital technologies to spread.

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performance, concluded disheartened that he could "see the *computer age* everywhere, but in productivity statistics" (SOLOW R., 1987).

[2] See DAVID P.A. (1991) and ROSSI S. (2003).

[3] See OECD (2002) and ROSSI S. (2003).

[4] See LIPSEY R.G. *et* AL. (2006, pages 114-1167). Empirical literature on the matter is voluminous, among others OLINER S.D. and SICHEL D.E. (2000) and JORGENSON D.V. and STIROH K.I. (2000) contributed.

In this regard, one point has won a growing consensus among scholars: namely, the need to accompany the purchase of digital appliances with collateral investments in firm reorganization and workers re-training. Bearing in mind the specificity of digital capital – a kind of equipment that need appropriate productive structures to actually bring about efficiency gains – the importance of such collateral investments appears self-evident. Empirical evidence on the matter is overwhelming, so much that Brynjolfsson and Hitt (2000) show how digital investments, if not backed with an adequate re-thinking of the production process and a careful preparation of the labour force, often turn out to be less profitable than investment in traditional capital.

In line with this thread of research is the evidence that a qualified workforce is at any rate an essential pre-condition for the successful adoption of new technologies; a result hardly surprising considering how sophisticated digital equipment is, and how re-training of labor force need to be carried out on skilled workers to be effective. As showed by Fabiani *et* al. (2005) and Padoan and Luciani (2007) in fact, digital adoption positively correlates with several dimensions of human capital and quality of the workforce (namely, the number of white-collars as a share of total employees, the age and education of employees and other such measures).

But other factors are equally important in shaping companies' willingness to undertake digital investments. By and large, firms that have invested most in digital technologies are also those who have much to gain from a better coordination of large information flows. Hence, both in Europe and in the USA firms invest heavily in ICTs when they work in the service sector (Van Ark and Inklaar, 2005 and Caselli and Games Paternò, 2003), whereas in Italy only big and medium sized companies operating in territories with high levels of economic activity have undertaken a serious commitment in adopting digital technologies (Fabiani *et* al., 2005).

Despite the rising interest that the determinants of digital diffusion have excited, researchers have relatively neglected the argument dealt by in this paper: namely, the role played by finance in promoting ICTs adoption. With the exception of only few contributions[5], economists need much less effort to see a positive contribution of the ICT revolution to the financial development rather than the other way round (Hobijn and Jovanovic, 2001 and Stiglitz, 2003). This is unfortunate, since, even though digital diffusion obviously played a part in the recent financial boom, the idea that causality ran in only one direction (*from* computers *to* financial development) is simplistic and it overlooks all too easily the fact that financial constraints are ideal candidates for explaining firms' difficulties in undertaking challenging and uncertain investments such as the digital ones.

Building upon the last observation, the paper takes up the study of the relationship between finance and ICT diffusion analysing with econometrical tools the dynamics of digital investments in fifteen industrialized countries.

The results of the analysis point to the importance of stock market development and suggest that *market-based* systems encourage digital investments better than *bank-based* ones. The estimates also suggest the existence of a negative and significant relationship between credit market development and firms' propensity to invest in ICT. Such a result though – significant as it may appear – is possibly driven by the dynamics of the rate of interest, a variable which in principle is able to affect in opposite directions both the share of digital investments and the amount of credit granted to the private sector. By and large, the evidence is consistent with theories that stress the effective selection of projects carried out by stock markets and the positive role of new financial tools usually traded within the markets of capitals in encouraging the adoption of digital technologies.

The paper is organized as follows. Section 2 tackle the issue of how financial institutions direct and shape firms' investment decisions; section 3 present the econometrical estimates of the relationships between finance and ICT diffusion; section 4 comments the results while section 5 concludes.

[5] The analysis of POZZOLO A.F. (2003) will be discussed shortly. YARTEY C.A. (2006), dealing with an issue quite similar, shows how the dimension of financial system promotes ICT diffusion among the population. His results cannot be applied for our purposes though, since the adoption of these technologies by the population measures only imperfectly their actual use within the production process.

2. - Finance and Digital Technologies

To understand why finance shapes firms' decisions and the dynamics of investments, one needs to consider how every firm, in order to carry out its projects of investments, needs to resort to either of two forms of financing: internal – when it draws on its own means – or external – when it turns to outside institutions. The *financial system* is the whole complex of agents and institutions (deposit money banks and business banks, stock markets and financial brokers) which, in different ways, help firms to collect and direct economy's savings towards the financing of their projects.

Oversimplifying a bit, it can be said that financial systems perform four major functions within the economic system (Levine, 1997 and 2005): 1) they mobilize economy's savings; 2) they contribute to efficiently allocate the resources of the economy; 3) they facilitate the exchange, the diversification and the management of risk and finally 4) they exert different forms of monitoring and control over firms' managers.

Though performing the very same functions, financial system may nevertheless develop along two substantially different structures. We talk of *bank-based* system – when the bank system issues the bulk of firms' financing – and of *market-based* system – if companies collect funds mostly through instruments traded within the stock markets. Building on these considerations, most of the literature on finance has thus followed either of two strands: namely, the analysis of the "finance-growth" nexus and the study of relative merits of different financial structures.

The works on the link between finance and economic growth spring from the seminal contributions of Robinson (1954), Goldsmith (1969) and Hicks (1969), and are by now countless. Here, we only go through some of the studies that analyzed this link focussing on the relationship between finance and innovation; for a complete review on the matter see the works of Levine (1997 and 2005). On theoretical grounds, King and Levine (1993*b*) made the point that the four functions performed by financial systems are especially important to promote innovative projects. In particular, they argue that the correct evaluation of entrepreneurs and their projects, the effective diversification of risks and the *pooling* of enough resources to overcome investments indivisibilities are key for the success of innovative ventures. Acemoglu *et* al. (2006) take the discussion one step further, and build a model where financial constraints shape firms' innovative strategy, determining whether they develop new technologies or else adopt inventions introduced by others.

Empirical analysis have generally confirmed the positive relation between finance and growth. On cross-sectional databases, King and Levine (1993*b*) have showed that banks development positively correlates with economic growth, capital accumulation and total productivity growth; Levine and Zervos (1998) have broadened these results and have showed that stock markets too influenced the rate of economic growth. Time-series analysis also detect a positive relationship between finance and level of activity, though they sometime raise the issue of causality (Arestis and Demetriades, 1997; Darrat, 1999).

Although the strand of literature that focussed on the relative merits of different financial structures has also produced an immense amount of research, a consensus is still far from being reached. As a matter of fact, even though there are theoretical reasons for favouring both *bank-based* and *market-based* structures (Levine, 2005), empirical research does not support either of these alternatives (Beck and Levine, 2002). However, although a clear case one way or the other can not be established, several studies have noted that banks systems are generally ill-suited to support innovation, not only because banks appropriate most of the benefits from investments (Weinstein and Yafeh, 1998), but also because financial markets are more effective in backing uncertain ventures for which the evaluation of investors differ widely (Allen and Gale, 1999).

Following the main tracks laid down by this literature, we shall study the relationship between finance and digital technologies along two threads: namely, the role of financial development in general and that of the particular structure which the systems takes.

Financial Development. Pozzolo (2003), dealing with the role of financial constraints in conditioning firms' inclination to purchase digital capital, does not find any significant correlation between financial development and ICT diffusion. Analysing the balance structure of a sample of Italian firms in fact, the author only finds that companies operating in the digital sector heavily depends on innovative financial instruments, whereas, as to the firms that only adopt new technologies, he is not able to show any significant correlation between liabilities structure and firms' willingness to purchase new technologies.

Despite these results, it is worth noting that the study focuses on only one country followed for a relatively short time (five year at most), and that Pozzolo himself admits that it might overlook subtler channels through which finance influences innovative investments. In particular, the sheer observation that the share of bank-backed financing of innovative companies is not significantly different from that of other firms, should not be offhandedly interpreted as an evidence of identical financial need for the two groups of firms. Rather, it might suggest a structural inefficiency of the bank system which – in Italy as elsewhere – is incapable of selecting and promoting profitable but uncertain projects such as those in digital technologies (Rajan, 1992 e Weinstein and Yafeh, 1998).

These *caveats* are all the more important since several reasons do suggest that financial development drive firms' propensity to adopt innovative technologies. In particular, at least four aspects deserve close consideration: namely, financial system's role in mobilizing savings; the support it offers in the projects' risk management; the financial institutions' backing of particularly illiquid investments and their action in shaping the productive structure of the country.

1. The four functions performed by finance are all activities in principle subject to strong scale economies that are best carried out in broad and highly developed financial systems. In this respect, the existence of a large number of agents working in a competitive market should reduce the share of savings withheld by brokers and dealers as a compensation for their intermediation,

thus guaranteeing that the highest fraction of savings collected is actually channelled to the financing of productive investments (Padoan and Mariani, 2006). Moreover, the width and depth of financial system allow to take advantage of information management scale economies, thus helping the agents to effectively select the most productive projects.

With these considerations in mind, it is easy to apply here the ideas of King and Levine (1993*b*). In fact, it is clear that thorough availability of financial resources and effective selection of best projects are key factors in promoting the adoption of new technologies, and that the services offered by financial systems might turn particularly useful to enterprises that wish to undertake demanding projects such as those involving digital equipment. These observation are all the more important, as digital investments require a commitment that does not end with the sheer purchase of new equipment, because it must be complemented with collateral investments that are usually big enough to double the expenses required.

2. It has also already been noted how the action of a large number of dealers working in a wide market where information is widespread and reliable, contribute to a better diversification and management of the risks associated to backed ventures.

Such contribution is especially important for firms that intend to invest in ICT, because it allows them to easily find resources for projects that, needing a radical re-thinking of company's organization and of production's structure, are subject to a high degree of uncertainty in the results and volatility in the profits.

3. The activity of financial institutions is also crucial in sustaining and promoting investments in highly illiquid assets. It is only the confidence in the support of external financers that make firms willing – in an uncertain world – to *sink* large amount of capital in activities that not only will yield profits in the long run alone, but most important can not be readily realized in case of emergencies (Hicks, 1969).

These considerations are quite appropriate in this context because, even though ICT capital should not be considered much more *sunk* than other forms of equipment, digital technologies require major expenses in the reorganization of the production, a kind of investment highly immaterial that by its very nature is locked up in the company that carries it out.

4. There is another channel through which financial development might have had a part in the diffusion of digital technologies: namely, the influence exerted by finance on industrial structure in general and on the small firms' level of activity in particular.

It has been noted in fact, that countries with highly developed financial system also have lively small firms so that different measures of financial development positively correlate with small companies business value (Guiso *et* al., 2004). This relationship is extremely interesting for our purpose since ICT adoption actually becomes convenient only beyond a certain level of activity[6], so that dampening or promoting small firms' expansion, financial systems may indirectly influence not only their propensity to purchase new technologies, but also the overall diffusion of digital equipment within the economy[7].

FINANCIAL STRUCTURE. Following along the thread set down in the last point, a few observations about the link between finance and the new start-ups are called upon. So far we have dealt with the influence of financial institutions on the decisions of firms *already on the market*, leaving in the background the financial demands of newly established firms. However, the link between the financial system and the development of new firms is a strong one, first and foremost because new entrepreneurs have no access on their own to large amount of finance and they always need to rely on the external support of financial institutions.

The success of innovative *start-ups* is all the more important bearing in mind how the diffusion of new technologies must necessarily come about through either of two channels: namely,

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[6] ROSSI S. and TRENTO S. (2003) talk of a "threshold effect".

[7] The effect of financial development on firms' size – constraining as it is for the diffusion of new technologies – does not determine any particular balance structure in innovative firms liabilities and therefore can not emerge in an analysis such as that carried out by POZZOLO A.F. (2003).

through the conversion of the production of already operating firms or else though the development of new firms that intensively employ new technologies. It is the major role played by digital *start-ups* in American ICT diffusion, that urge a careful analysis of the factors which contributed to their success[8].

To this end, it is worth recalling Schumpeter's theories (1911), as they held the financial system to be the major responsible for the growth of a capitalistic economy. According to this view, the importance of financial institutions can be fully understood only once we recognise how new enterprises do not all have the same requirements of external finance, and how innovative *start-ups* are more likely to be highly dependent on borrowed money than newly established firms working in traditional sectors. This is so, not only because most of the time innovative entrepreneurs are *outsiders* with respect to the economic system[9], but also because the very nature of their projects forces them to undertake very high fixed costs hardly sustainable without the help of external financing.

The major role played by innovative *start-ups* in the digital sector and the specificity of their financial demands, prompt the question of whether there is a particular financial structure that can best meet their demands. Being understood that the access to a wide and efficient financial system is a key factor to promote the birth and development of new enterprises, it might actually be more interesting to ask "*which* finance – rather than *how much* finance – serves best the needs of new digital *start-ups*?" Several elements do suggest that the development of a large stock market and a *market-based* financial structure might be important elements for the success of the most innovative *start-ups*.

To show this point, one needs to consider the specific outline of firms working in the digital sector. Most of these company in fact, are relatively small firms, whose major assets are highly immaterial (most of the time they are either patents or projects-in-progress) and in general lacking large funds on their own. Their

[8] See ROSSI S. (2003).

[9] «... it is not the owner of stage-coaches who builds railways» jokes Schumpeter to make his point (SCHUMPETER J.A., *op.* cit., page 68).

financial needs are very different from those of newly established traditional firms, to the point that several authors have suggested that such activities are so little transparent and difficult to control, to entail prohibitive costs for traditional institutions in terms of information collection and management monitoring[10]. Traditional banks in particular, are very reluctant to grant funds to these firms, since the returns of the digital sector, high as they may be on average, are too much volatile to be borne by cautious banks.

Where *start-ups* in the digital sector experienced strong success though, their financing has been carried out to a substantial degree through innovative financial instruments issued by agents mostly working within markets of capitals[11]. The most common of such innovative instruments are the *venture capitals* and the *angel financings*, contracts that, if on the one hand need wide and lively capital markets to spread, on the other hand may actually loosen some of the financial constraints curbing the growth of newly established digital firms.

As it turns out, the brokers dealing with these contracts, not only are ready to accept high uncertainty in the returns but, more important yet, they are usually skilled advisors with long experience and deep knowledge of the sector they are investing in. Therefore, they are able not only to justly assess the value of projects, but at times even to involve themselves in the direct management of firms. The action of these financers does not narrow down to funding: the *venture capitalists* play a key role in selecting the most promising projects for the firms, in supervising the different stages of development of the company and sometimes even in suggesting potential course of expansion (Lerner, 1995; Hellmann and Puri, 2002). Moreover, *venture capital* backed *start-ups* find also easier to access banking credit[12], and quite often reach a size large enough for their shares to be traded in the stock market.

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[10] See LERNER J. (1995).

[11] This was certainly the case for the United States, but POZZOLO A.F. (2003) shows that in the Italian digital sector too, newly established firms extensively resorted to these kind of financing.

[12] POZZOLO A.F. (2003) suggests that banks may trust the close control carried out by *venture capitalists*.

It is precisely the prospect of the listing in the capital markets the crucial condition for these financial contracts to successfully spread, since the existence of a developed and lively stock market where companies need not to be large to have their shares traded, works as a warrantee for *venture capitalists* and entrepreneurs alike. Once the firm has developed enough for its shares to be exchanged in the stock market in fact, the creditors know that they are not bound to the financed firm indefinitely (stock market firms assets are easily tradable), whereas the entrepreneurs can downsize the bargaining power of the *venture capitalist* drawing on the external funding they can raise in the stock market (Hellmann and Puri, 2002).

To summarize what has been suggested so far, the *trait d'union* which would link the financial structure to the success of digital technologies might run through the diffusion of new financial tools such as the *venture capitals* and the *angel financings*. Given that these contracts have proved particularly effective in financing the *start-ups* of the digital sector, and given the need of well-developed capital markets in order for these instruments to diffuse, it is all too natural to conclude that stock market development might have had a major impact in promoting the diffusion of digital technologies. Even though it is not clear why the banking sector should not take advantage of the new financial instruments, as a matter of fact even where banks do offer funding through *venture capitals*, the practise is not quite common and the digital sector perform relatively poorly[13].

3. - Empirical Evidence

In order to test the theories put forward in the second section, the link between ICT diffusion and several dimensions of financial development has been examined through the specification of an

[13] German banks hold most of *venture capitals* issued in the country (Pozzolo A.F., 2003), but the digital sector is still under-developed and hardly innovative ([German] Federal Ministry of Education and Research, 2006).

error *correction model* (ECM) run over a *panel* of yearly macroeconomic data for fifteen industrialized countries (the United States and the European Union without the Luxembourg[14]) followed for a period of twenty-five years (from 1980 to 2004).

The ICT diffusion in the countries considered is measured through gross fixed capital formation and gross fixed capital stock of *hardware* and *software* equipment[15], whereas five distinct variables intend to give account of different dimension of financial development and structure.

More specifically, the five financial variables taken are those employed in several studies about financial systems[16] and refer to: 1) stock market dimension; 2) bank credit development; 3) overall development of the financial system (measured as the dimension of the stock market *and* of the bank sector together); 4) the actual level of activity of the system and 5) the particular structure showed by the financial system (either *bank-based* or *market-based*).

The variable that accounts for the stock market development (*stkmrk*) equals the value of listed shares divided by GDP and intends to measure the size of the stock market. The variable that measures credit market development (*cred*) equals the claims on the private sector by deposit money banks divided by GDP[17]. Financial dimension (*dim*) equals the sum of money banks assets and stock market capitalization divided by the GDP. Whereas the

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[14] The European countries are Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden and the United Kingdom. The exclusion of Luxembourg is necessary since the country is an *outlier* for most of the time series considered.

[15] Data come from the database created by the Groeningen Growth and Development Centre – GGDC (TIMMER M.P. *et* AL., 2005). Table 1 summarizes data definitions and sources.

[16] Data come from the database constructed by BECK T. *et* AL. (1999 and 2000) with series from the IMF's *International Financial Statistics* (INTERNATIONAL MONETARY FUND, 2006).

[17] Deposit Money Banks are "all financial institutions that have liabilities in the form of deposits transferable by check or otherwise usable in making payments". The definition of "deposit money bank" is close – though not identical – to that of "commercial banks" which are institutions that accept deposits and make business loans (BECK T. *et* AL., 1999). The authors refer to "deposit money banks" because the *IFS* database from which they have built their series defines consistently across countries only this variable.

TABLE 1

LIST OF VARIABLES

Variable	Code	Definition	Source	Time span
IT Gross Fixed Capital Stock at current prices	K_c^{IT}	Computer, Office Machinery and Software Capital Stock (current prices)	GGDC	1980-2004
Total Gross Fixed Capital Stock at current prices	K_c^{TOT}	Total Capital Stock at constant (2000) (current prices)	GGDC	1980-2004
IT Investments at current prices	I_c^{IT}	Computer, Office Machinery and Software Gross Capital Formation (current prices)	GGDC	1980-2004
Total Investments at current prices	I_c^{TOT}	Total Gross Fixed Capital Formation (current prices)	GGDC	1980-2004
IT Capital Deflactor	d^{IT}	Computer, Office Machinery and Software capital deflactor (2000 = 1)	GGDC	1980-2004
Total Capital Deflactor	d^{TOT}	Total Capital Deflactor (2000=1)	GGDC	1980-2004
IT Gross Fixed Capital Stock at constant prices	K_b^{IT}	K_c^{IT}/d^{IT}	GGDC	1980-2004
Total Gross Fixed Capital Stock at constant prices	K_b^{TOT}	K_c^{TOT}/d^{TOT}	GGDC	1980-2004
IT Investment at constant (2000) prices	I_b^{IT}	I_c^{IT}/d^{IT}	GGDC	1980-2004
Total Investments at constant (2000) prices	I_b^{TOT}	I_c^{TOT}/d^{TOT}	GGDC	1980-2004
Gross Domestic Product	GDP	Gross Domestic Product at current prices	GGDC	1980-2004
IT Factor Input Compensation Share	s^{IT}	Average Compensation share in GDP for IT Capital	GGDC	1980-2004
Total Capital Factor Input Compensation Share	s^{TOT}	Average Compensation share in GDP for all Capital	GGDC	19802004
IT Depreciation Rate	δ^{IT}	IT depreciation rate (imputed values)	GGDC	1980-2004
Total Capital Depreciation Rate	δ^{TOT}	All capital depreciation rate (imputed values)	GGDC	1980-2004
Inflation	*p*	Rate of Inflation	IMF-IFS	1980-2004
Stock Market Development	*stkmrk*	Stock Market Capitalization/*GDP*	WB-BDKL	1989-2004
Credit Market Development	*cred*	Money Bank Credit to Private Sector/*GDP*	WB-BDKL	1980-2004
Financial Dimension	*dim*	(Money Bank Assets + *stkrmk*)/*GDP*	WB-BDKL	1989-2004
Level of Financial Activity	*act*	(Money Bank Credit to Private Sector + Stock Market Value Traded)/*GDP*	WB-BDKL	1989-2004
Financial Structure	*struct*	Money Bank Assets/Stock Market Capitalization	WB-BDKL	1989-2004
Own calculations based on these data				
IT Capital Stock as a share of Total Capital	k^{IT}	K_b^{IT}/K_b^{TOT}		
IT Investment share at current prices	y_c^{IT}	I_c^{IT}/I_c^{TOT}		
IT Investment share at constant (2000) prices	y_b^{IT}	$1n(I_c^{IT}/I_c^{TOT})$		
Logarithm of IT Investments share at current prices	*y*	I_b^{IT}/I_b^{TOT}		
IT Capital Factor Input Compensation	C^{IT}	s^{IT} * *GDP*		
Total Capital Factor Input Compensation	C^{TOT}	s^{TOT} * *GDP*		
Real Returns of IT Capital	R^{IT}	$(C^{IT}/K_c^{IT}) - \delta^{IT} - p$		
Real Returns of Total Capital	R^{TOT}	$(C^{IT}/K_c^{IT}) - \delta^{IT} - p$		
Logarithm of Real Returns of K^{IT} divided Real Returns of K^{TOT}	*r*	$\ln(R^{IT}/R^{TOT})$		

- Data of gross capital formation and stocks come from the *Total Economy Growth Accounting Database* (GGDC) organized by TIMMER M.P. *et* AL. (2003) at the *Groeningen Growth and Development Centre* at the Groeningen University and publicly available at: *http://www.ggdc.net/databases/ted_growth.htm*. Original data of this database come from the national statistics institution of each country.
- Financial data come from the database prepared by BECK T. *et* AL. (1999 and 2000) for the World Bank (WB-BDKL). The latest version of the database (updated to the 2008) is available online at: *http://siteresources.worldbank.org/INTRES/Resources/4692321107449512766/FinStructure_2007.xls*. Original data come from the International Monetary Fund's *International Financial Statistics* (IMF-IFS).
- Data on each country's inflation come from the INTERNATIONAL MONETARY FUND (2006) who organizes the *International Financial Statistics* (IMF-IFS). The database is downloadable from: *http://www.imf.org/external/data.htm* upon subscription.
- Total capital is the sum of IT capital (computer, office machinery and software), telecommunication equipment, transport equipment, non-residential structures and non-ICT capital. Such decomposition is performed by the *Groeningen Growth and Development Centre* (GGDC).
- The variables that measure the real returns of IT and total capital (R^{IT} and R^{TOT}) have been computed as explained in the text with data from the *Groeningen Growth and Development Centre* database (GGDC) and with the inflation series taken from the *International Monetary System's International Financial Statistics* database (IMF-IFS).

money bank credits to the private sector used in *cred* only include claims to the private sector, the money bank assets used here include claims on the whole non-financial real sector, including government and public enterprises. The level of activity (*act*) equals the sum of money bank credits to the private sector and of the stock market value traded to the GDP. The banks credits are defined as above, while the stock market value traded is computed as the value of all the shares traded on the stock market exchange. Thus, the two variables used to construct the measure of financial activity are slightly different insofar as the money bank credit to the private sector also measures the amount of *new* financing issued by the banks, whereas the stock market value traded does not. However, several works have pointed out that stock market capitalization does not represent faithfully the actual activity of markets (Levine and Zervos, 1998), also because tax systems may encourage the listing of firms, thus artificially boosting the variable (Rajan and Zingales, 1998). Finally, the financial structure (*struct*) is measured as the *ratio* between money bank assets and stock market capitalization, a quantity which defines how much the banking sector is developed with respect to the capital markets[18].

3.1 *The data*

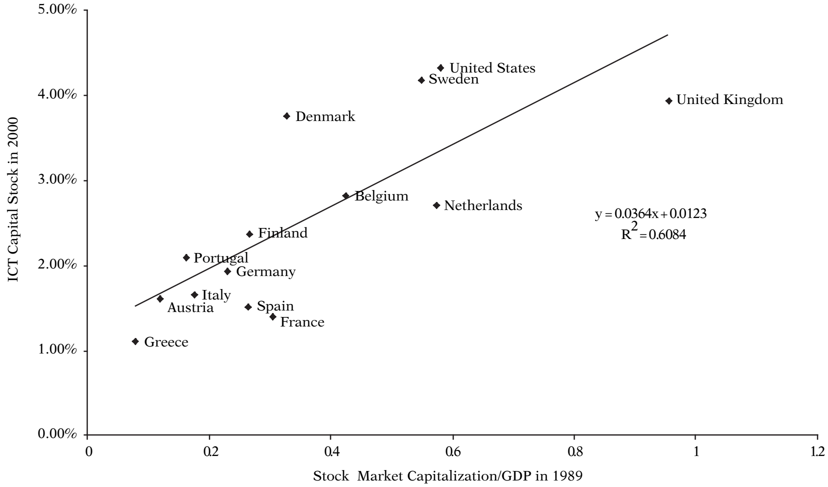
Before introducing the results of the econometric model, a qualitative analysis of data gives a rough idea of the major points that will emerge from a rigorous study.

The scatterplots showed in Graphs 1-5 relate the share of *hardware* and *software* stock over total stock of capital in 2000 (on the *y*-axis) to the values taken by the five financial variables at the start of the observation period (on the *x*-axis). While the ICT variable should give a measure of the actual diffusion of digital technologies within the production systems in 2000, the financial

[18] Thus, the variable takes high values in *bank-based* system and much lower ones in *market-based* systems.

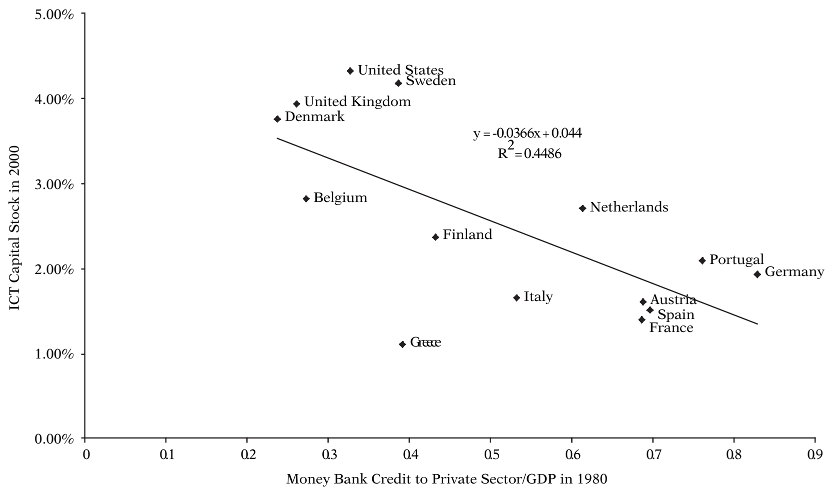
GRAPH 1

ICT CAPITAL STOCK AS A SHARE OF TOTAL CAPITAL IN 2000 AGAINST STOCK MARKET CAPITALIZATION IN 1989



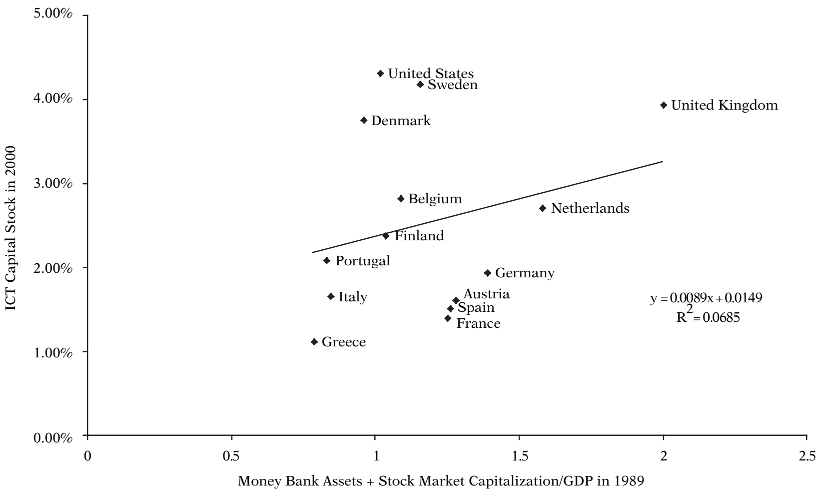
GRAPH 2

ICT CAPITAL STOCK AS A SHARE OF TOTAL CAPITAL IN 2000 AGAINST CREDIT MARKET DEVELOPMENT IN 1980



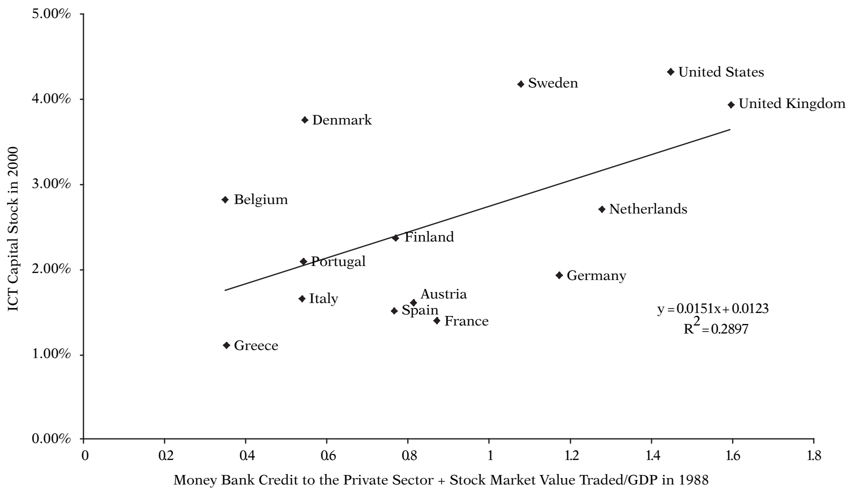
GRAPH 3

ICT CAPITAL STOCK AS A SHARE OF TOTAL CAPITAL IN 2000 AGAINST OVERALL FINANCIAL DIMENSION IN 1989



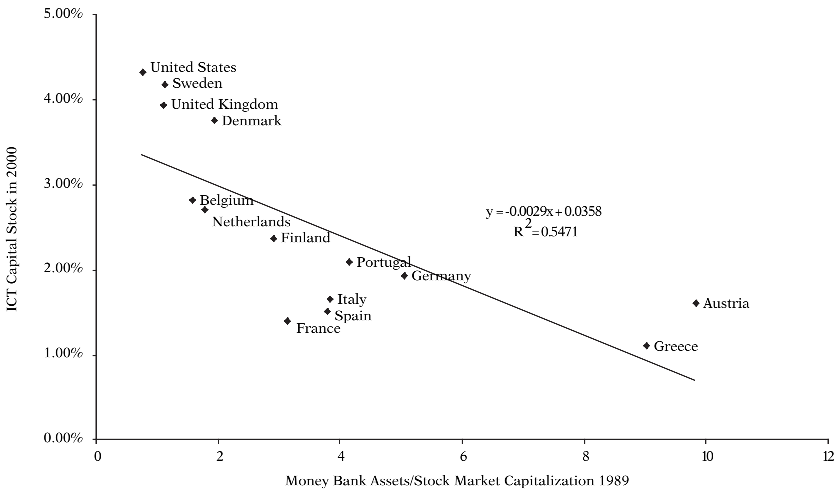
GRAPH 4

ICT CAPITAL STOCK AS A SHARE OF TOTAL CAPITAL IN 2000 AGAINST FINANCIAL ACTIVITY IN 1988



GRAPH 5

ICT CAPITAL STOCK AS A SHARE OF TOTAL CAPITAL IN 2000 AGAINST FINANCIAL STRUCTURE IN 1989



variables give an idea of different dimensions of financial development some years before. Together the information should highlight any causal relation between financial systems' development in the eighties and the ICT accumulation process which took place in the following years[19].

Three major patterns emerge from the analysis of the figures. Firstly, both stock market capitalization and the overall level of financial activity at the end of the eighties appear to positively correlate with the share of ICT capital stock in 2000; in particular, stock market capitalization shows quite a significant relationship[20]. Secondly, by contrast, bank credit development and overall financial

[19] Resorting to past values of financial variables should prevent – to some extent – the error of detecting a spurious relation where the ICT diffusion actually drives the financial development in the analysed countries. A similar procedure was adopted by KING R.J. and LEVINE R. (1993*a*) in order to study the finance and growth nexus.

[20] The coefficient of the regression between IT capital share in 2000 and stock market capitalization in 1989 equals +0,036 with a R^2 of 60 percent. As to the overall activity level regression coefficient, it equals +0,015 with a R^2 of almost 29 percent.

dimension do not exhibit an equally robust positive relationship: the development of the credit market in 1980 even appear to negatively correlate with the share of ICT equipment twenty years later, whereas the total dimension of the financial system does not seem to have influenced the ICT accumulation pattern over the following years[21].

Lastly, particularly interesting appears the relationship between the financial structure at the end of the eighties and the digital capital stock in 2000. Graph 5 highlights how countries with *market-based* financial structure in 1989 systematically show very high shares of digital capital stock ten years later (the pattern is striking for the four countries with the lowest *ratio* of bank asset to stock market capitalization: United States, Sweden, United Kingdom and Denmark). By contrast, countries where the bank sector controls most of the financing show in 2000 digital capital shares substantially lower than the average (the cases of Austria and Greece are exemplary).

3.2 *The Error Correction Model*

Arestis and Demetriades (1997) review the principal limitations of studying the impact of finance on real economy using a cross-section framework. In particular, they note that, whereas cross-country regressions can only assess the "average effect" of a variable across countries, the impact of finance is likely to be substantially different across economies (see also Darrat, 1999)[22]. Its is for these reasons that we decided to exploit fully

[21] The regression coefficients are -0,037 for the credit market development and +0,009 for the overall financial dimension; estimated R^2 equalled respectively 45 and 7 percent. Obviously, results drawn from these regressions are hardly significant, first and foremost because OLS estimates run with only one explanatory variable at a time may suffer of a severe omitted variables problem. The purpose so far is only to give a rough description of data, possibly avoiding too hazy assessments.

[22] Other limitations of the cross-section approach are the sensitivity of results to the set of conditioning variables, the asymptotic bias of the estimated coefficient on the convergence term and the issue of causality, which cannot be satisfactorily addressed in a cross-section framework (ARESTIS P. and DIMITRIADES P.O., 1997).

the time dimension of the variables, specifying fifteen ECM models and testing for *panel* cointegration.

In these regressions we use as dependent variable the share of IT gross fixed capital *formation* at current prices rather than the share of ICT capital *stock*. Even though the two variables are obviously intertwined, what matters to our purposes is the dynamics of firms' investment decisions, a process that the investments series reveal better than the capital stocks ones. In fact, while the share of digital equipment over the total stock of capital also depends upon the different dynamics of capital obsolescence and usage, the value of digital purchases as a share of total investments gives an immediate measure of the actual propensity of firms to undertake projects with new ICT equipment.

Before showing the model, some brief comments on the choice to express the dependent variable in current prices are maybe appropriate. The choice of using time series in current price in fact, although unusual, is made necessary by the especially inconvenient behaviour of the constant prices ICT investments series. Graph 6 depicts the dynamics of the share of *hardware* investments at current (the dashed line) and at constant prices (the continuous line), and shows how the constant prices series exhibit a pattern quite different from other types of investments (see Graph 7).

Being y_c and y_b the shares of digital investments respectively in current and constant prices, the two series depicted in Graph 6 come from the two equations:

$$y_c = \frac{I_c^{IT}}{I_c^{TOT}}$$

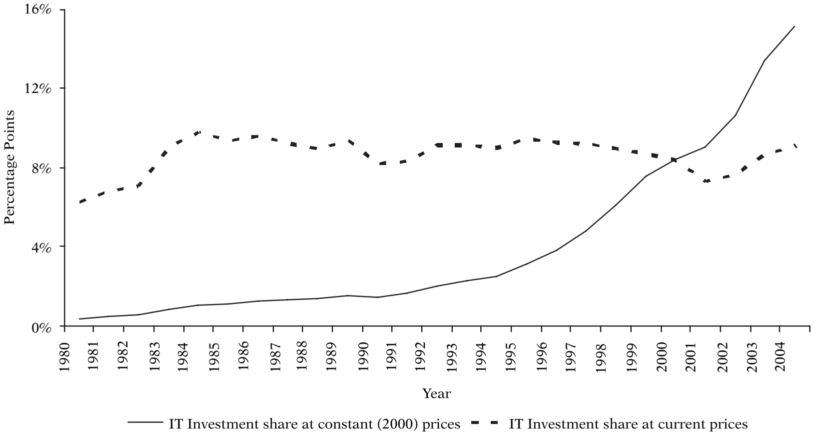
(1)

$$y_b = \frac{I_b^{IT}}{I_b^{TOT}} = \frac{I_c^{IT}}{d^{IT}} \cdot \frac{d^{TOT}}{I_c^{TOT}} = y_c \cdot \frac{d^{TOT}}{d^{IT}}$$

where $d^{TOT} = \frac{I_c^{TOT}}{I_b^{TOT}}$ e $d^{IT} = \frac{I_c^{IT}}{I_b^{IT}}$ and are respectively total investments and hardware investments deflators. From *(1)* it is clear that what makes the two series behave differently is the *ratio* between the

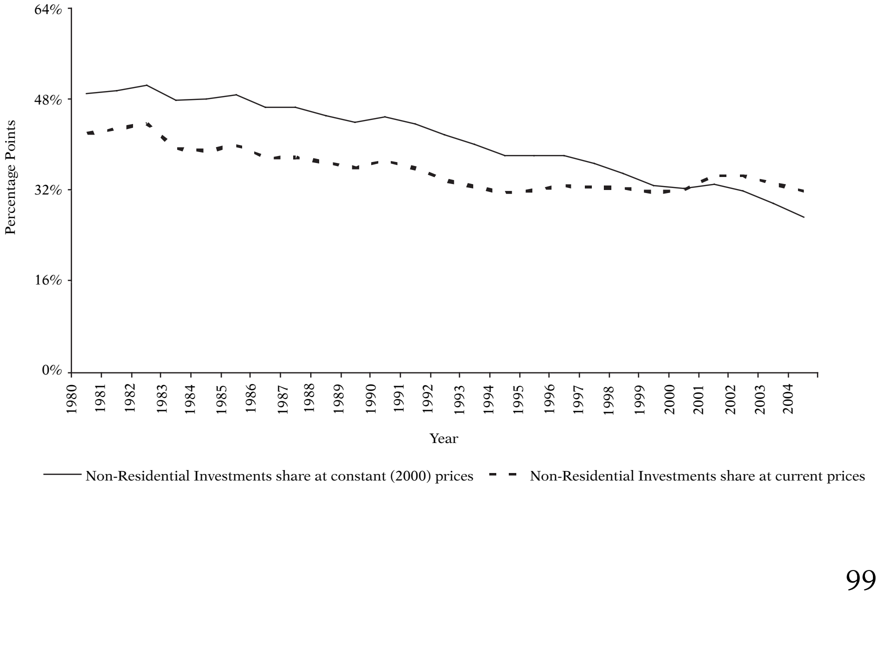
GRAPH 6

IT INVESTMENTS SHARES IN USA



GRAPH 7

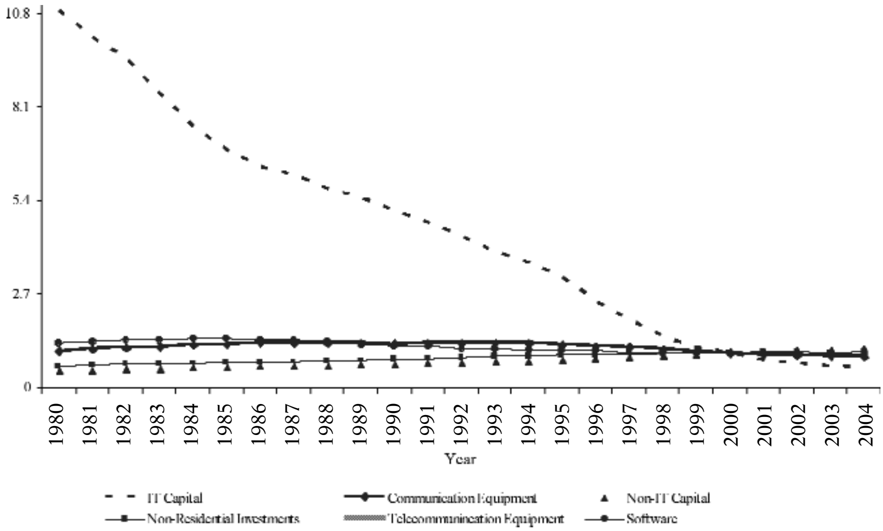
NON-RESIDENTIAL INVESTMENTS SHARES IN USA



deflators of total and IT investments. Although such assertion is true for any investment, only in the case of *hardware* investments a problem arises, since digital equipment has undergone a depreciation process much faster than any other type of capital, a phenomenon which led its deflator to show a behaviour quite different from other types of investments (see Graph 8).

GRAPH 8

RATIOS OF THE DEFLATOR OF TOTAL CAPITAL TO DEFLATORS OF SINGLE KINDS OF CAPITALS*



* Cf. eq. *(1)*.

Bearing in mind that the price fall of digital equipment depends primarily on the improvement of goods quality[23], constant price series do not allow to appreciate firms' IT purchasing real commitment, a problem which is particularly severe for early observations. On the other hand, current prices series have the great advantage that can be immediately taken as a measure of firms *propensity* to invest in digital technologies. At

---

[23] DAVID P.A. (2001) and AIZCORBE A. and PHO Y. (2005) discuss the issue and assess the different contribution to prices fall coming from quality improvements and traditional market forces (larger supply for instance).

any given year, the share of IT investments at current prices reflects the actual commitment of firms in adopting digital technologies, and this irrespective of the value that this equipment has at the base year. Clearly, dealing with current prices time series, one should not mistake the dependent variable as a direct measure of digital technologies *diffusion* within production at any rate because digital equipment purchased at the start of the '80s has lost 9/10 of its value twenty-five years later.

The study has been organized as follows. First, fifteen "baseline" ECM equations have been estimated: these equation do not include any financial variable so that the variability of the digital investments share is explained by one single explanatory variable with which it shows a long-run and stable relationship. Drawing upon economic literature[24], it has been built a proxy for the *ratio* between the real returns of digital capital over the real returns of total capital used in the economy.

The fifteen baseline ECM equation specify this relationship:

$$\Delta y_{it} = \beta_{0i} + \alpha_i \cdot (y_{it-1} - \beta_{1i} \cdot r_{it}) + \gamma_i \cdot \Delta y_{it-1} + \varepsilon_{it} \qquad (2)$$

where $y_{it} = \ln\left(\frac{I_{it}^{IT}}{I_{it}^{TOT}}\right)$ stands for the natural logarithm of digital investments as a share of total investments for country *i* over the year *t*; while $r_{it} = \ln\left(\frac{R_{it}^{IT}}{R_{it}^{TOT}}\right)$ is the natural logarithm of the *ratio* of the real returns of ICT capital over the total returns of capital in the economy. These variables have been derived in a given year as the *ratio* of the GDP compensation share to each capital divided the value of the capital itself, net of its depreciation and of each country's inflation rate. Hence:

$$R_{it}^{IT} = \frac{C_{it}^{IT}}{K_{it}^{IT}} - \delta_{it}^{IT} - \dot{p}_{it} \text{ e } R_{it}^{TOT} = \frac{C_{it}^{TOT}}{K_{it}^{TOT}} - \delta_{it}^{TOT} - \dot{p}_{it}$$

[24] The reference here is DIXIT A.K. - PINDYCK R.S. (1994).

where C_{it} K_{it} δ_{it} and $\dot{p}_{it}$ stand respectively for the capital compensation, the value of the capital stock used, its depreciation rate and the inflation rate in country i over the year t[25].

Once the cointegration relationship has been established between investments and their real return, the five financial variables were added to the ECM regression conveniently differentiated:

$$\Delta y_{it} = \beta_{0i} + \alpha_i \cdot (y_{it-1} - \beta_{1i} \cdot r_{it}) + \gamma_i \cdot \Delta y_{it-1} + \varphi \cdot \Delta f_{it} + \varepsilon_{it} \tag{3}$$

The five financial variables were added one at a time in five separate systems, so that the relationships between the dependent variable and the five different financial dimensions could be singled out and examined.

The need to specify a "baseline" regression without any financial variable arises from several considerations. Firstly, unit root tests presented in Tables 2-4 indicate that y_{it} and r_{it} have been non-stationary over the period under consideration and suggest to analyse their dynamics within a cointegration framework. This raises a delicate issue, in particular because assuming that the share y_{it} is *~I(1)* implies that it could wander off 1 or 0. However, economic theory suggests to interpret these results as an evidence of a shift in both variables *over the period under consideration*. Obviously, this is not to say that these variables will always be *~I(1)*; rather, it is to accept that since 1980 IT investment shares have experienced considerable persistence, and that IT capital enjoyed returns increasingly higher than other types of capital, conclusions that are broadly in line with much of the literature on ICT (David, 2001 and Brynjolfsson *et* al., 2002).

Secondly, economic theory and empirical research have not established any long-run relationship between investments and finance. As a matter of fact, whereas extended research has documented the positive impact that finance had on growth over the past 50 years, similar evidence does not exist for the

[25] Factor input compensation series come from *Total Economy Growth Accounting Database* developed by the *Groeningen Growth and Development Centre* who computes it through a growth accounting exercise (TIMMER M.P. *et* AL., 2003).

investment-finance nexus and Beck *et* al. (2000) even conclude that the long run relation between financial development and capital formation is "tenuous". Obviously finance might still exert a major impact in the short run, but over the long run investments are primarily linked to their returns (Wurgler, 2000). Moreover, beside these theoretical considerations, the fact that the available financial time series were rather short (up to only fifteen years) imposed the necessity to single out at least one variable able to explain most part of investments' variations, so that the relationship between finance and IT investment may be established simply considering whether financial variables do explain the part of investments' volatility for which real returns do not account.

3.3 *Empirical results*

Tables 2-4 summarize the results of the unit root tests run over the digital investments shares and the *ratio* between real returns of IT capital over total capital returns. The test is an *Augmented Dickey-Fuller* (ADF) and for both variables it has been carried out on both level- and first-difference series in order to check for integration order higher than 1. Critical values used are not those tabulated by Dickey and Fuller (1979) but the less conservative ones estimated by Blangiewicz and Charemza (1990) for unit root tests on small samples.

The estimates show how all series are *~I(1)* except France's digital investments share and the *ratio* of real returns of Austria and the United States. Despite the inconclusive results of the unit root tests, a decision has been taken and all series have been considered as random draws from non stationary *~I(1)* process. The choice was driven both by the consideration of the little power of the ADF test (even when adjusted critical values are used) and by the opportunity to keep all series and analyse the dynamics of a wider sample of countries[26].

[26] The choice – arbitrary as it is – was encouraged by the fact that the results of *panel* unit root tests run on the *panels* of the two variables lead to reject the

TABLE 2

ADF TESTS ON *y*

Country	Levels			First Differences		
	t statistics	Lags	Decision (5% confidence)	*t* statistics	Lags	Decision (5% confidence)
Austria	-1.96	0	Accept H_0	-4.39**	0	Reject H_0
Belgium	-2.51	0	Accept H_0	-3.99**	0	Reject H_0
Denmark	-2.83	0	Accept H_0	-6.3**	0	Reject H_0
Finland	-1.27	0	Accept H_0	-4.47**	0	Reject H_0
France	-3.48	1	Accept H_0	-2.26	0	**Accept H_0**
Germany	-2.53	1	Accept H_0	-2.89*	0	Reject H_0
Greece	-1.02	0	Accept H_0	-5.42**	0	Reject H_0
Ireland	-2.92	0	Accept H_0	-4.24**	1	Reject H_0
Italy	-2.54	4	Accept H_0	-6.83**	0	Reject H_0
Netherlands	-1.84	0	Accept H_0	-3.85**	0	Reject H_0
Portugal	-2.10	0	Accept H_0	-3.46*	0	Reject H_0
Spain	-3.30	1	Accept H_0	-2.67+	0	Reject H_0
Sweden	-0.23	0	Accept H_0	-3.45*	0	Reject H_0
United Kingdom	-0.36	0	Accept H_0	-4**	0	Reject H_0
United States	-3.05	0	Accept H_0	-4.32**	0	Reject H_0

** stands for 1% significance; * for 5% and + for 10%.

TABLE 3

ADF TESTS ON *r*

Country	Levels			First Differences		
	t statistics	Lags	Decision (5% confidence)	*t* statistics	Lags	Decision (5% confidence)
Austria	-2.83	2	Accept H_0	-2.34	0	**Accept H_0**
Belgium	-2.40	0	Accept H_0	-4.13**	0	Reject H_0
Denmark	-3.38	2	Accept H_0	-2.52+	0	Reject H_0
Finland	-1.91	1	Accept H_0	-2.70+	0	Reject H_0
France	-2.72	1	Accept H_0	-2.47+	0	Reject H_0
Germany	-2.80	1	Accept H_0	-3.78**	2	Reject H_0
Greece	-3.24	0	Accept H_0	-6.83**	0	Reject H_0
Ireland	-2.43	1	Accept H_0	-2.65+	0	Reject H_0
Italy	-2.24	1	Accept H_0	-2.84*	0	Reject H_0
Netherlands	-3.39	2	Accept H_0	-2.42+	2	Reject H_0
Portugal	-2.27	1	Accept H_0	-2.75+	0	Reject H_0
Spain	-1.83	0	Accept H_0	-3.66**	0	Reject H_0
Sweden	-2.86	1	Accept H_0	-2.70+	0	Reject H_0
United Kingdom	-0.98	0	Accept H_0	-5.30**	0	Reject H_0
United States	-2.15	1	Accept H_0	-2.22	0	**Accept H_0**

** stands for 1% significance; * for 5% and + for 10%.

TABLE 4

ORDER OF INTEGRATION

Country	*y*	*r*
Austria	I(1)	**I(2)**
Belgium	I(1)	I(1)
Denmark	I(1)	I(1)
Finland	I(1)	I(1)
France	**I(2)**	I(1)
Germany	I(1)	I(1)
Greece	I(1)	I(1)
Ireland	I(1)	I(1)
Italy	I(1)	I(1)
Netherlands	I(1)	I(1)
Portugal	I(1)	I(1)
Spain	I(1)	I(1)
Sweden	I(1)	I(1)
United Kingdom	I(1)	I(1)
United States	I(1)	**I(2)**

As to the study of the order of integration of the financial variables, it was primarily intended to establish whether or not these series were second- or higher-order integrated. As shown by equation (3) in fact, financial variables enter in the *error correction* equation already differentiated, and they are never considered in the cointegration relationship. As the equations stand, it becomes unimportant to establish whether or not the financial series share the same order of integration of the other two variables, and it is sufficient to check only for the stationarity of the first-difference series put into the regression.

Table 7 summarizes the unit root tests run over the five financial series. Here too, Blangiewicz and Charemza (1990) adjusted critical values have been considered in order to account

hypothesis that the *panels* were second order integrated (see Tables 5-6). Also CHRISTOPOULOS D.K. - TSIONAS E.G. (2004) use results from *panel* unit root tests to decide the order of integration of a set of variables for which ADF tests gave inconclusive indications.

TABLE 5

PANEL UNIT ROOT TESTS ON *y*

Levels					
Method	Statistics	p-value	Decision	Cross-sections	Observa-tions
Levin, Lin and Chu's *t*-statistics§	-7.65	0	**Reject H_0**	15	344
Im, Pesaran and Shin's *W* statistics†	-4.85	0	**Reject H_0**	15	344

§ Null hypothesis assume one single unit root process.
† Null hypothesis assume individual unit root processes.

TABLE 6

PANEL UNIT ROOT TESTS ON *r*

Levels					
Method	Statistics	p-value	Decision	Cross-sections	Observa-tions
Levin, Lin and Chu's *t*-statistics§	-3.11	0.001	**Reject H_0**	15	334
Im, Pesaran and Shin's *W* statistics†	1.96	0.97	Accept H_0	15	334
First Differences					
Method	Statistics	p-value	Decision	Cross-sections	Observa-tions
Levin, Lin and Chu's *t*-statistics§	-4.83	0	Reject H_0	15	328
Im, Pesaran and Shin's *W* statistics†	-6.28	0	Reject H_0	15	328

§ Null hypothesis assume one single unit root process.
† Null hypothesis assume individual unit root processes.

for small sample distortion. As the table shows, every series appear to be at most first-order integrated except Belgian financial structure and two Finnish variables (namely stock market and private credit development). These second-order integrated series have been left out of the study of the finance-IT investments relationship since they would specify regressions between series with different order of integration.

Economic theory suggests the existence of a direct relationship between investments and their expected real returns (Dixit and Pindyck, 1994 and Wurgler, 2000); as long as firms are adaptive in forming their expectations, predicting future returns similar to present ones, investments and real return dynamics will

TABLE 7

SUMMARY OF ADF TESTS ON FINANCIAL SERIES

Country	*stkmrk*			*cred*			*dim*			*act*			*struct*		
	t-stats (Levels)	*t*-stats (1° (Differences)	Order of integration	*t*-stats (Levels)	*t*-stats (1° (Differences)	Order of integration	*t*-stats (Levels)	*t*-stats (1° (Differences)	Order of integration	*t*-stats (Levels)	*t*-stats (1° (Differences)	Order of integration	*t*-stats (Levels)	*t*-stats (1° (Differences)	Order of integration
Austria	-2.20	-4.27**	I(1)	-2.19	-4.59**	I(1)	-7.08**		I(0)	-1.95	-6.10**	I(1)	-4.66*		I(0)
Belgium	-2.08	-3.13*	I(1)	-1.89	-2.84*	I(1)	-6.08**		I(0)	-1.78	-4.45**	I(1)	-1.67	-2.27	**I(2)**
Denmark	-3.64	-4.03**	I(1)	-3.82*		I(0)	-2.03	-2.67^{+}	I(1)	-4.14*		I(0)	-2.34	-2.89**	I(1)
Finland	0.09	-2.85	**I(2)**	-3.04	-1.37	**I(2)**	-2.51	-4.14**	I(1)	-2.51	-2.92*	I(1)	-0.68	-2.44+	I(1)
France	-5.89**		I(0)	-3.26	-2.89*	I(1)	-2.14	-3.71**	I(1)	-2.88	-3.64**	I(1)	-3.43	-3.82**	I(1)
Germany	-2.29	-3.84**	I(1)	-4.15*		I(0)	-1.89	-3.84**	I(1)	-4.52*		I(0)	-2.52	-4.04**	I(1)
Greece	-4.40*		I(0)	-3.03	-3.11*	I(1)	-3.36	-3.57*	I(1)	-1.88	-3.83**	I(1)	-4.19*		I(0)
Ireland	§	§	§	-1.45	-3.52*	I(1)	§	§	§	§	§	§	§	§	§
Italy	-3.56	-3.67**	I(1)	-2.78	-3.06*	I(1)	-0.73	-3.28*	I(1)	-2.75	-4.20**	I(1)	-3.71	-3.33**	I(1)
Netherlands	-4.37*		I(0)	-2.30	-4.20**	I(1)	-5.15**		I(0)	-1.62	-4.13**	I(1)	-12.65**		I(0)
Portugal	-3.31	-3.13*	I(1)	-0.72	-2.74^{+}	I(1)	-1.27	-3.11*	I(1)	-1.10	-3.05*	I(1)	-3.12	-2.04	**I(2)**
Spain	-2.14	-3.73**	I(1)	-2.27	-3.32*	I(1)	-1.55	-3.49*	I(1)	-3.51	-3.40*	I(1)	-1.20	-3.69**	I(1)
Sweden	-1.75	-2.87*	I(1)	-3.78*		I(0)	-2.51	-2.82*	I(1)	-2.55	-3.11*	I(1)	-1.16	-2.51^{+}	I(1)
United Kingdom	1.84	-2.65^{+}	I(1)	-2.69	-3.68**	I(1)	-1.38	-4.40**	I(1)	-1.58	-4.88**	I(1)	-0.56	-2.69*	I(1)
United States	-3.11	-3.27*	I(1)	-1.88	-3.55*	I(1)	-7.84**		I(0)	-2.93	-2.51^{+}	I(1)	0.49	-2.47^{+}	I(1)

§ For Ireland, only *cred* had a series long enough to allow the ADF test to be carried out.
** stands for 1% significance; * for 5% and $^{+}$ for 10%.

be closely related. Building on this framework the model assumes that the dynamics of IT expenditure as a share of total investments was driven by the *ratio* between the real returns of digital capital over real returns to total capital.

The observation that both series were first-difference stationary suggested to arrange the analysis within a cointegration framework estimating an *error correction model* for each country. As already shown the "baseline" equations on which the relationship between IT investment share and the ratio of returns was established was:

$$\Delta y_{it} = \beta_{0i} + \alpha_i \cdot (y_{it-1} - \beta_{1i} \cdot r_{it}) + \gamma_i \cdot \Delta y_{it-1} + \varepsilon_{it} \tag{4}$$

where symbols maintain specified meaning.

The estimation method is a *seemingly unrelated regressions model* (SURE) first introduced by Zellner (1962), which not only leaves coefficients β_{1i} free to take up different values, but it also allows for the co-variability of different countries' series to be taken into account through their variance-covariance matrix.

Table 8 summarizes estimations, significance and some statistics of regressions *(4)*, whereas Table 9 shows the results for the unit root tests run on the error series ($y_{it-1} - \beta_{1i} \cdot r_{it}$) of the same equations. Together, the results bring support to the hypothesis of cointregration between the two variables for thirteen out of the fifteen countries considered.

Error correction coefficients α_i are all negative and greater than -1: an encouraging result that not only supports the existence of an error correction mechanism, but also rules out the possibility of an explosive dynamics driven model. Moreover, error correction coefficients are all extremely significant (to 1 percent confidence level) except for the Sweden (significant to 5 percent level, however) and United Kingdom.

But still more interesting is the result concerning the unit root tests run over the error correction components. The tests are ADF, and critical values are once more those estimated by Blangiewicz and Charemza (1990) for unit root tests on small sample cointegrated series residuals (CRADF; again less conservative than

TABLE 8

SURE ESTIMATES FOR THE "BASELINE" ECM EQUATIONS

Country	β_0	α	β_1	γ	R^2	*DW* Stats
Austria	-0.05	-0.47**	1.00**	0.1	41%	1.92
Belgium	-0.88**	-0.53**	0.11	0.29**	37%	2.14
Denmark	0.06	-0.27**	0.89	-0.11	26%	1.94
Finland	-0.17	-0.21**	0.47	0.06	20%	1.9
France	0.17	-0.24**	1.77**	0.75**	57%	2.35
Germany	-0.23*	-0.35**	0.69**	0.40**	61%	2.08
Greece	-0.66**	-0.19**	-0.24	-0.07	66%	1.69
Ireland	-1.79	-0.56**	-0.16	0.2	31%	2.01
Italy	-0.58**	-0.28**	0.14	-0.07	30%	1.87
Netherlands	0.19*	-0.80**	1.19**	0.35**	56%	1.84
Portugal	-2.01**	-0.46**	-0.68*	0.58**	37%	2.06
Spain	-0.74**	-0.47**	0.39**	0.34**	84%	2.1
Sweden	-0.1	-0.20*	0.48	0.17	32%	1.52
United Kingdom	-0.84*	-0.08	-4.32	-0.12	52%	1.4
United States	0.80**	-0.75**	1.39**	0.31**	62%	1.88
Average §			0.539			

§ The average is computed without Sweden and United Kingdom coefficients.
** stands for 1% significance; * for 5% and + for 10%.

TABLE 9

ADF TESTS ON THE ERROR CORRECTION COMPONENT OF THE "BASELINE" ECM EQUATIONS

Country	*t*-statistics	Lags	Decision (1% confidence)
Austria	-4.34**	0	I(0)
Belgium	-4.69**	0	I(0)
Denmark	-4.31**	0	I(0)
Finland	-4.25**	0	I(0)
France	-5.29**	0	I(0)
Germany	-4.55**	0	I(0)
Greece	-3.76**	0	I(0)
Ireland	-4.69**	0	I(0)
Italy	-4.18**	0	I(0)
Netherlands	-5.22**	0	I(0)
Portugal	-5.02**	0	I(0)
Spain	-4.61**	0	I(0)
Sweden	-3.35	0	**I(1)**
United Kingdom	-3.22	0	**I(1)**
United States	-4.78**	0	I(0)

** stands for 1% significance; * for 5% and + for 10%.

those tabulated by Engle and Yoo, 1987). The estimates lead to reject the null hypothesis of non-stationarity for all series but those of Sweden and United Kingdom, a result that, together with the significance of the α_i coefficients for these countries, allows to accept the cointegration relationship for thirteen of our fifteen countries.

A second supporting result is the estimated sign for the β_{1i} coefficients. With the exception of Portugal, Ireland and Greece in fact, IT investments share turns out to positively correlate with the *ratio* of real returns of digital capital over all kinds of capital, a result consistent with economic theory predictions. On average[27] the coefficients of the *ratio* of real returns equal 0.53, but estimates register marked differences among countries. In particular, while those countries that least invested in digital technologies (Greece and Portugal in the forefront) record negative coefficients between dependent and explicative variables, those who did most so exhibit very high coefficients, in some cases greater than unity. Firms' propensity to invest in IT was very strong in the United States and in the Netherlands, where high values of β_1 match estimates of the error correction term quite close to -1, a signal of high speed in the error correction dynamics. Particularly intriguing is the case of France, where the strong relation estimated with the β_{1i} is coupled with a value of α quite close to zero. Apparently French firms, though driven by returns when planning their investments, are extremely slow in adjusting their behaviour to the changing dynamics of profits.

In order to utilize data in the most efficient manner, we checked whether the relationship established between the two variables could be fitted within a panel cointegrated model with a unique long-run $\overline{\beta}_1$ and different short-run β_{1i} (Pesaran *et* al., 1999). Unfortunately, the Wald test performed on the β_1s estimates a χ^2 statistics of 90.4, a value which leads to decidedly reject the null hypothesis that a unique $\overline{\beta}_1$ drives the dynamics across countries. The result prevents from specifying a unique *panel*

[27] The average was calculated without the coefficients of Sweden and United Kingdom.

cointegrated model, and thus takes us back to the study of thirteen separated equations.

The results of the Wald test would be quite disappointing if the analysis were based on standard tests. In fact, as Christopoulos and Tsionas (2004) argue, *panel* cointegrated models are a particularly convenient way to analyze short *panels*, since they make sure that standard tests do not suffer of power loss due to finite samples. As explained throughout however, power loss of standard tests was always controlled for by considering less conservative critical values tabulated by Blangiewicz and Charemza (1990); moreover, we also maximized efficiency by estimating with a method (the SURE) that allows to take account of the co-variance of series. Inevitably, results presented are more heterogeneous than they would have been with a *panel* cointegrated model but, as Arestis and Demetriades (1997) and Darrat (1999) argue, this need not to be a drawback, as the impact of finance on the economy is likely to differ substantially across countries.

In the following, the relationship between finance and IT diffusion will be analysed on thirteen separated equations.

As showed by equation *(3)* the influence of finance on IT diffusion is analysed simply adding financial variables to the ECM equations estimated. For convenience we rewrite equation *(3)*:

$$\Delta y_{it} = \beta_{0i} + \alpha_i \cdot (y_{it-1} - \beta_{1i} \cdot r_{it}) + \gamma_i \cdot \Delta y_{it-1} + \varphi_i \cdot \Delta f_{it} + \varepsilon_{it} \qquad (5)$$

where symbols keep their meaning and f_{it} are natural logarithms of the five financial variables.

Financial variables have been inserted individually in five separate systems, while Swedish and British regression have never been estimated since the basic variables of the ECM did not appear to co-integrate. Table 10 summarizes the estimates of φ_{it} coefficients in equations *(5)*.

Only considering systems' significant coefficients, the regressions point to a strong positive relation between stock market development and IT diffusion and to a quite robust negative influence of credit market development on firms' propensity to invest on digital technologies.

TABLE 10

SUMMARY OF FINANCIAL COEFFICIENTS

Country	*stkmrk*	*cred*	*dim*	*act*	*struct*
Austria	0.05	0.35	-0.18	-0.28	0.04
Belgium	0.09	-0.57**	-0.57**	-0.08	–
Denmark	0.03	-0.09*	-0.01	-0.06	0.00
Finland	–	–	0.09**	0.09	-0.04
France	0.01	-0.57**	0.20	0.07	-0.07**
Germany	0.03	-0.36	-0.15	-0.17**	-0.03
Greece	0.16**	0.48	0.43**	0.19**	-0.11**
Ireland	–	–	–	–	–
Italy	0.01	0.01	0.07	0.01	-0.03
Netherlands	0.05**	0.04	0.06*	0.00	-0.04*
Portugal	0.37**	0.47	-0.46	0.27	–
Spain	0.00	-0.14	-0.05	-0.03	-0.01
Sweden	–	–	–	–	–
United Kingdom	–	–	–	–	–
United States	0.12**	-0.57**	0.03	-0.09*	-0.15**
Average§	0.18	-0.45	0.03	-0.02	-0.10

§ The average is computed only with significant coefficients.
** stands for 1% significance; * for 5% and + for 10%.

On the contrary, the study of the two variables giving account of the financial system overall development brings less conclusive results: financial systems dimension and activity show significant coefficients only in three countries, and in general coefficients turn out to be quite low (in Belgium financial dimension coefficient turns out to be negative; in the United States and in Germany it is the financial activity to show a negative relationship). The low significance showed by these variables may however be the result of the opposite effects of two different components of the financial variables on the dependent variable, as they are built as the sum of separate elements referring to stock market and to bank sector development.

Finally, the results of the regressions with the financial structure turn out extremely interesting. As it happens, not only all significant coefficients are negative (that is, those of France, Greece, the Netherlands and the United States), but breaking the sample along the financial structure of countries, β_{1i} coefficients driving the relationship between investments and real returns in *market-based* countries score a value almost twice as high as that of *bank-based* ones[28]. Since the financial structure variable grows as the bank sector gains importance over the stock market, the estimated signs should point to a negative influence of *bank-based* systems on firms' willingness to invest in digital equipment, and in general they bring support to the idea that *market-based* systems best encourage IT investments. The next section comments these results.

4. - The Results

Before commenting on the results, it is worth to point out some facts about the variable with which the IT investments share cointegrate.

A close look to the dynamics showed by the IT capital to total capital returns *ratio* reveals that, over the whole period, in every country considered, digital investment have been yielding on average real returns three and a half times higher than total capital. Such a difference – impressing as it may be – is not surprising: at any rate it tells a story quite similar to the one told by other microeconomic studies (Brynjolfsson *et* al., 2002). Very high returns associated to IT investments are usually explained with company's reorganization costs: investments that have proven quite difficult to be kept on records but that need nevertheless to be adequately compensated.

The evidence of investments collateral to the purchase of digital appliances is consistent with most of the literature which has dealt with IT diffusion but it also suggests a first interpretation of the results. If it is correct to relate digital expenditures to other

[28] The average coefficient β_{1i} in *market-based* countries is 1.074; for the *bank-based* group of countries the same value equal 0.575. *Bank* or *market-based* structure has been established comparing each country financial structure average to the average over the whole sample of countries. Denmark, Finland, France, the Netherlands and the United States show a stock market capitalization to money bank assets *ratio* lower than the average, whereas Austria, Germany, Greece, Italy and Spain exhibit a value greater than the average.

sort of investments such as production restructuring, it is all too natural to imagine that such projects also entail a higher risks and a need for funds greater than traditional investments. Following this track, and bearing in mind the importance of financial institutions in granting funds and easing risk management, the positive relationship between some financial variables and IT diffusion seems logical.

But other comments may be drawn on the estimates proposed. In particular, three major points can be made.

• Firstly, it is important to note that only few countries show significant coefficients for the financial variables. Such evidence is not surprising, and it should not be taken as a proof of the little influence of finance on firms' investments decisions. Rather, the low significance of coefficients could depend either on the little time-variation of financial variables, or on the financial systems' high level of integration.

Even though the little variability of financial variables might help in explaining the results, these series are far from being flat, and thus the financial integration explanation still retains some appeal. According to this interpretation in fact, the possibility of companies to access foreign funding loosen the financial constraint imposed to firms by local financial systems and allows the dynamics of national investments to be fairly independent on national finance fluttering (Guiso *et* al., 2004). The results proposed do lend support to such an interpretation, as long as significant coefficients are detected mostly for those countries whose firms – for different reasons – must rely more heavily on national financial systems.

This is the case for the United States and Greece in particular, whose financial coefficients turn out to be significant in four cases out of five. In these countries, the distance from other financial systems, the financial system's dimension itself (this is the case of America) or structural limits (this is the case of Greece) restrain firms' accession to foreign finance and by this token closely link investments' possibilities to the expansion of national finance. It is the very significance of these countries' coefficients to suggest caution and to ward from jumping to the easy conclusion that low significance of other coefficients simply reflects little influence of finance over IT adoption.

• Estimates highlight a second major result: namely, the positive relationship between stock market development and firms' propensity to invest in IT. It is so suggested not only by the stock market capitalization regression results (the financial coefficient is significant in four countries – always with the plus sign) but also by the analysis carried out on ECM equation augmented with the financial structure variable (significant in four countries and always with a negative sign). Such results suggest that where a finance-IT diffusion nexus does emerge, it usually comes about through the stock market influence on firms' investments choices. Moreover, the evidence is also consistent with theories which hold the diffusion of innovative financial instruments such as *venture capitals* and *angel financings* as a decisive factor for IT firms success.

Of course, financial markets growth and digital technologies diffusion are two phenomena closely related, and it would be unfair to conclude that causation ran only one way (*from* stock market development *to* IT capital adoption). As every industry working on large information flows, financial sectors had much to gain from the digitalization of production and – still more important for countries like the United States – the results of companies in the digital sector explained a great deal of the nineties stock market boom. As a matter of fact, the positive coefficient between stock market capitalization and IT investments share only highlights a positive relation between the two variables, an evidence that could lend support to a positive influence either of capital markets on ICT diffusion or the other way around.

One piece of evidence does suggest to hold stock market development as responsible for ICT diffusion though: namely, the results of the ECM equation including the financial structure variable. Built as the *ratio* of money bank assets over stock market capitalization, the variable is meant to measure the relative size of the banking sector with respect to capital markets and thus should not be subject to any particular influence from the ICT investments variable. Given the huge gains digital technologies have brought to the financial sector, there is no reason to believe that stock markets should have enjoyed higher productivity dividends than the banking sector, and thus there is no reason to argue for the numerator and denominator of financial structure variable to be differently influenced by the ICT diffusion. For our purposes then, the evidence of a negative coefficient for the variable representing *bank-based* financial structures lends some support to the thesis of a positive effect of stock market development on digital adoption.

• Finally, another quite robust result comes from the negative coefficient of the credit market development variable.

It is luring to take this evidence together with the second strong result and to ascribe the negative influence of both *bank-based* systems and credit market development to the risk aversion of banks and their low propensity to back very uncertain projects.

Although banks attitude towards risky ventures is obviously an important factor when analysing the funding of ICT investments, such an interpretation might overlook some important aspects. In fact, the relationship between IT investments share and money banks credit to private may be driven by an omitted variable, outside the regression, but all the same capable of influencing both variables in opposite directions. In this respect, the rate of interest might be an ideal candidate for influencing the two variables.

Money banks credits issued to the private sector is a variable that also includes bank loans to households, whose dynamics are obviously sensible to the rate of interest fluctuation, at any rate because high rates would discourage households to bid for loans. On the other hand, IT expenditure over total investments is a variable possibly positively correlated with the rate of interest, for high rates force companies to discriminate against less profitable investments and to choose only those projects that promise high returns. As IT capital has showed returns much higher than the other types of capital throughout the period considered, it is correct to imagine that digital investments share grow as the rate of interest goes up.

On the same note, one would argue that the negative relation between credit market development and IT investments share is primarily driven by the rate of interest dynamics, and not – not *only* at least – by a negative influence of bank finance development on digital technologies adoption.

In fact, these conclusions are strengthened by the observation that the negative relationship between credit market development and IT investments share does not arise in those countries where digital capital yielded returns quite similar to those yielded by the rest of capital. This is the case of Portugal and Greece – the two countries of the sample where ICT returns were lowest – that show a positive (though non-significant) coefficient of the credit market development variable. Such evidence suggests that where IT investments experienced returns in line with those yielded by other kinds of capital, the rate of interest does not influence the dynamics of digital investments share, which in turn does not turn out to be negatively correlated with credit market development.

5. - Conclusions

The paper examines with econometrical tools the relationship between finance and the adoption of digital technologies by firms. While the interest in digital technologies stems from the productivity gains brought about by these devices, the attention to the link between finance and the diffusion of these technologies draws on theories that have stressed the role of financial institutions in advising and directing firms' investment choices.

The paper introduces an empirical analysis which exploits co-integration tools to study the relation between the share of digital investments and five different dimensions of financial development. As a general pattern, financial coefficients turn out to be significant only in countries whose firms – for different reasons – must necessarily rely on national financial systems (this is the case for the United States and Greece for instance); a result that confirms the high degree of integration attained by European financial systems, and should not be taken as an indication of little influence of finance over firms' investments choices.

In this respect instead, statistical estimations carry evidence of a positive role played by stock market development and suggest that *market-based* systems encourage digital investments better than *bank-based* ones. The results also highlight a negative and significant relationship between credit market development and firms' propensity to invest in IT, a result that however may be driven by the dynamics of the rate of interest, a variable in principle capable to affect in opposite directions both the share of digital investments and the amount of credit issued to the private sector.

By and large, the evidence is consistent with theories that stress the effective selection of projects carried out by stock markets and the positive role of new financial instruments (*venture capitals* and *angel financings* are the most common) usually traded within the stock markets in encouraging the adoption of digital technologies.

It is worth noting that the *macro* nature of data used only allows for a "coarse-grained" photography of such phenomena. In particular, one might speculate that even though financial integration has made the domestic system less relevant for many companies, home finance still plays a relevant role in promoting innovative projects and the development of new firms. However, such hypothesis are best investigated through *micro* analysis based on firm- and sector-level data which are beyond the scope of this paper. As a matter of fact, the *macro* results so far proposed do suggest that the finance-ICT nexus is a topic worth further research.

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