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The effect of hard and soft information and communication technologies investment on manufacturing business performance in Greece – A preliminary econometric study

Euripidis N. Loukis [a,*], Ioakim A. Sapounas [a], Alexandros E. Milionis [b]

[a] Department of Information and Communication Systems Engineering, University of the Aegean, 83200 Karlovassi, Samos, Greece
[b] Department of Statistics and Actuarial – Financial Mathematics, University of the Aegean, 83200 Karlovassi, Samos, Greece

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Abstract

This paper presents the results of the first empirical investigation of the effect of information and communication technologies (ICT) investment on business performance in Greece. It investigates the effect of both 'hard' ICT investment (in ICT hardware, software and networks) and 'soft' ICT investment (in ICT human resources, skills and organization) on firm output. It is based on data from big Greek industrial firms, which have been collected via a questionnaire-based survey conducted in cooperation with the Federation of Greek Industries (FGI). Using these data, econometric models of output have been constructed based on the microeconomic production theory. Our analysis shows that the Cobb–Douglas production function can adequately describe the output, as compared to the more general transcendental production function. Using this type of production function it has been found that hard ICT investment in Greece makes a positive and statistically significant contribution to firm output; however its output elasticity is lower than the one of the non-computer capital and much lower than the one of the labour. Also, from the dimensions-measures of the soft ICT investment we examined, it has been found that the existence of a separate ICT department has a positive and statistically significant effect on firm output, which is of considerable magnitude of about two thirds of the effect of the hard ICT investment. The possibility of an effect of firm size on the structural stability of the econometric models we employed was also investigated; it was found that for firms with total sales above about €20 million the structure of the models is reasonably stable, and therefore the conclusions drawn from them are valid, at least for the range of firm sizes that our data cover.

Keywords: Information and communication technologies hard investment; Information and communication technologies soft investment; Productivity paradox; Business performance; Production function; Effect of firm size

* Corresponding author. Tel.: +30 22730 82221; fax: +30 22730 82009.
E-mail address: eloukis@aegean.gr (E.N. Loukis).

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1. Introduction

Significant investments have been made by businesses in information and communication technologies (ICT) in the last 25 years (OECD, 2003, 2004), so it is of critical importance to investigate the benefits and the value they create and their effect on business performance. For this reason extensive research has been conducted in order to investigate the relation between ICT investment and business performance. The first period of this research, from the mid 1980s until the mid 1990s, contrary to theoretical arguments and professional beliefs, provided very little empirical evidence of a positive and statistically significant relation between ICT investment and business performance (e.g. Strassman, 1990, 1997). These early results alarmed managers, puzzled researchers and posed critical questions concerning the productivity of ICT investments, usually referred to as the 'ICT Productivity Paradox' (Brynjolfsson, 1993). However, the second period of this research, from the mid 1990s until today, has provided empirical evidence of positive and statistically significant relation between ICT investment and some measures of business performance (e.g. Brynjolfsson and Hitt, 1996; Stolarick, 1999). However, there are still studies leading to conclusions in the opposite direction (e.g. Stiroh, 1998; Hartman, 2002). These contradictory results indicate that there might be some additional variables that influence the effect of ICT on business performance, such as various characteristics of the sectoral and the national context of the firm, etc. so further research is required in this direction. Moreover, the research during this second period has found that the effect of ICT investments increases significantly if they are combined with some appropriate complementary 'co-investments' in creating new organizational practices and human skills, re-engineering business processes, etc., which enable a higher degree of exploitation of the capabilities and the potential of ICT (e.g. Bresnahan et al., 2002; Ramirez, 2003; Arvanitis, 2005); this finding provides another possible explanation for the above contradictory results. In this direction, as described in more detail in the next section, considerable research has been conducted mainly in the last 5–6 years in order to identify and understand such complementary actions and factors, usually referred to as 'ICT complements', which can increase the contribution of ICT investment to business performance.

However, the above research has focused on the 'hard' ICT investment, namely on the investment in ICT hardware, software and networks, while the effect of the 'soft' ICT investment, defined as the investment in ICT human resources, skills and organization, on business performance has been researched to a very limited extent; so the effect of this 'soft complement' of the 'hard' ICT investment on business performance remains unexplored, even though the relevant literature has emphasized its importance for the effective exploitation and use of the 'hard' ICT investment in accordance with the needs and the strategy of the particular firm (e.g. Stratopoulos and Dehning, 2000; Melville et al., 2004); from an extensive literature review Melville et al. (2004) conclude that further research is required concerning the effect of ICT on organizational performance covering both the 'Technological IT Resources' and the 'Human IT Resources' of organizations.

Also, most of the previous research on the effect of ICT investment on business performance in both these periods has been based mainly on empirical studies conducted in the context of a few countries, which are characterised by high levels of economic development and ICT penetration, although OECD warns that the impact of ICT investment can differ significantly across countries (OECD, 2003, 2004). In the same direction Melville et al. (2004) from their literature review conclude that one of the most important gaps of the research conducted in this area is its 'emphasis on US firms' and 'lack of cross-country studies', so its 'results are conditional on the characteristics of the US business environment'.

This paper contributes to filling the above research gaps. It presents the first econometric study of the effect of ICT investments on manufacturing business performance in Greece, based on data from big Greek industrial firms, which have been collected through a questionnaire-based survey in cooperation with the Federation of Greek Industries (FGI). It is quite interesting to investigate the above-mentioned research questions in Greece, taking into account its differences from the highly developed countries in which most of the empirical studies on this subject have been conducted. Greece does not belong to the highly developed countries, though it has made considerable economic progress in the last decade and has become a member of the European Economic and Monetary Union. It is characterised by smaller size of internal market, smaller average firm size, lower intensity of competition and lower level of ICT penetration and Internet usage than the highly developed countries ('Digital Strategy 2006-2013', 2005). According to Eurostat (http://epp.eurostat.ec.europa.eu/portal/) in 2005 the expenditure for IT hardware, equipment, software and other services in Greece was 1.2% of the Gross Domestic Product (GDP), while in the whole European Union it was much higher at the level of 3.0% of GDP; also, concerning Internet electronic commerce, in 2006 the sales that Greek firms conducted through the Internet were on average only 1.1% of their total sales, while in the whole European Union they reached the level of 4% of total sales. Also, Greece has some notable 'idiosyncratic characteristics' concerning corporate governance: in many firms, even in big ones, the majority of firm ownership belongs to members of the same extended family; furthermore, in many cases there is no distinction between ownership and management (the big shareholders are also the members of the board of directors). So it is of much interest to investigate the effect of these investments on business performance under such country specificities, which may affect firms' decisions concerning the use and the management of ICT, and therefore the generation of business value from them. However, the findings of this study will be interesting not only for Greece, but also for many other countries, which are not highly developed and have similar characteristics.

A second contribution of this paper is that it examines the effect on business performance not only of the 'hard' ICT investment, but also of the 'soft' ICT investment as well, which has received limited research attention as mentioned above; this 'soft' ICT investment is often neglected by the Greek firms (Sirigos, 2001) and we believe that this might happen also in other similar national contexts (at least to some extent). Also it is the first time that a comparison is made between the effects of these two types of ICT investment (hard and soft) on business performance, and also with the effects of the two 'basic' production inputs: the labour and the 'non-ICT' investment. A third contribution is that this study initially investigates which is the most appropriate form of production function to be used as a basis for addressing the above research questions in the Greek national context. While most of the previous relevant research has been based on production functions of the so-called Cobb–Douglas form (see Section 3 for more details), in this study we investigate whether a more general form of production function would be more appropriate; this issue has never been examined in the previous relevant research. Finally, a fourth contribution of this paper is that it examines for first time in such studies the effect of the firm size on the structural stability of the constructed econometric models, and therefore on the validity of the conclusions drawn from them, using a method based on the 'recursive residuals'.

The structure of the paper is as follows: initially in Section 2 as a background of this study a review of the previous research on the effect of ICT investment on business performance is presented; then in Section 3 the research hypotheses, method and data of the study are described, while in Section 4 the results are presented and discussed. Finally in Section 5 the conclusions are summarised and directions for further research are proposed.

2. Background

Extensive research has been conducted in the last 20 years in order to investigate the business benefits and value generated by the big ICT investments that firms have made, and their impact on various dimensions on business performance. Many empirical studies on this subject have been published, which differ in the level of analysis (there are studies at the national economy level, at the sectoral level and at the firm-level), the dependent variables (several business performance measures have been used), the independent variables, the methodology, the data and the context. Since our study focuses at the firm-level, in this section is reviewed the firm-level research that has been conducted in this area. As mentioned in the introduction, this research can be divided into two periods: a first period, between the mid 1980s and the mid 1990s, and a second period, from the mid 1990s until today.

2.1. First Period (mid 1980s–mid 1990s)

In this first period of this research, from the mid 1980s until the mid 1990s, very little empirical evidence has been found of a positive and statistically significant relation between ICT investment and business performance. Most of the studies of this period found zero or even negative impact of ICT investment on productivity. One of the first studies in this area was conducted by Roach (1987), who measured the productivity of information workers against that of production workers; he found that during the 1970s through the mid 1980s the productivity of production workers increased by 16.9%, while the productivity of information workers decreased by 6.9%, despite the big ICT investments that had been made during this period. Strassman

(1990, 1997), in three relevant studies he conducted in 1985, 1990 and 1994, found no evidence of a relation between ICT investment on one hand and profitability and productivity on the other. Weill (1992) examined the effect of ICT investment in transactional, informational and strategic IS on various measures of business performance in valve manufacturing firms; he concluded that only the investment in transactional IS is positively associated with some measures of business performance, while the investment on informational and strategic IS has no impact on business performance. Yosri (1992), based on data from large food firms, found that ICT investment is not associated with sales growth, market share gain, new market penetration, productivity and various measures of quality improvement. Loveman (1994) examined the benefits generated by ICT investment in business units of manufacturing firms between 1978 and 1984 using production function estimates; he found no evidence of a positive contribution of ICT investment to firm output; however, he found that non-ICT inputs are contributing positively to firm output. Hitt and Brynjolfsson (1996), based on data from large firms between 1988 and 1992, found that IT investment had increased productivity and consumer value, but did not increase profitability. Rai et al. (1996, 1997) found that the total IS budget makes a positive contribution to firm output and labor productivity, but not to the return on assets and the return on equity; also they found that different components of the IS budget have different effects on the various business performance measures. Similar conclusions were drawn by Barua et al. (1995), who found a positive effect of ICT investment on some measures of performance of important business processes, such as inventory turnover, etc., but they found no evidence of a positive effect at the level of the returns on assets. These unexpected and counter-intuitive findings posed critical questions concerning the impact of ICT investments, usually referred to as the 'ICT Productivity Paradox', which is summed up in R. Solow's statement that 'you can see the computer age everywhere but in the productivity statistics' (Solow, 1987). Brynjolfsson (1993), based on a review of the relevant literature of this first period, summarises the 'ICT Productivity Paradox' issue as follows: 'Delivered computing power in the US has increased by more than two orders of magnitude since 1970, yet productivity, especially in the service sector, seems to have stagnated'; also, in the same paper he remarks that the Productivity Paradox may be, at least to some extent, due to mismeasurement of outputs and inputs, mismanagement of ICT, redistribution of ICT benefits to the consumers (via an increase of consumer surplus) and also due to lags in learning, adjustment and restructuring of firms, which are necessary in order to reap the full benefits from ICT investments.

2.2. Second Period (mid 1980s until today)

The studies of Brynjolfsson and Hitt (1996) and Lichtenberg (1995) can be regarded as the starting point of a second period of research in this area, from the mid 1990s until today, which has provided empirical evidence of positive and statistically significant relation between ICT investment and business performance. Brynjolfsson and Hitt (1996) using an extensive data set on ICT spending by large US firms compiled by the International Data Group (IDG) and constructing econometric models founded on a Cobb–Douglas production function framework found that the contributions of computer capital and ICT staff labour expenses to firm output are not only positive and statistically significant, but also much higher than the contributions of the non-computer capital and the non-IS labour expenses respectively. Lichtenberg (1995) and Lehr and Lichtenberg (1999), using estimates of Cobb–Douglas production functions, came to similar conclusions: ICT investment contributes significantly to firm output and generates high levels of returns, which are much higher than the returns of the non-ICT investment. Dewan and Min (1997), using multiple econometric models provide consistent and confirmatory evidence of a positive relation between ICT investment and firm output. Gurbaxani et al. (1998), based on data from large firms belonging to the 'Fortune 1000' between 1987 and 1994, examine the returns to different kinds of computer hardware investments; using estimates of a Cobb–Douglas production function they found that investments in mainframe and PC hardware are positively associated with firm output. Devaraj and Kohli (2000) provide evidence of positive effect of ICT capital and labour on two important output performance measures in the health care industry (net patient revenue per day and net patient revenue per admission). Gilchrist et al. (2001) examine the effect of ICT on the performance of manufacturing firms between 1987 and 1994; their analysis shows that ICT contribute to productivity, and this contribution is higher than what would be expected given the share of ICT capital in the overall capital investment; also they found that the contribution of decentralised computing (e.g. PC technology) is higher than the contribution of centralised computing (e.g. mainframe technology). Devaraj and Kohli (2003) from a longitudinal study in hospitals conclude that the main driver of the impact of ICT on financial and non-financial performance is not the investment in technology, but the actual usage of technology. The positive evidence found in this second period concerning the impact of ICT investment on several measures of business performance reflects the improvements in ICT management, and also the adjustments and the restructuring that had taken place at the firm-level between the mid 1980s and the mid 1990s, which enabled a higher level of value and benefits from ICT; also it reflects the significant improvements in research methodology (e.g. in data collection and analysis). However, even in this second period there are studies leading to conclusions in the opposite direction (e.g. Stiroh, 1998; Hartman, 2002), which indicate that there might be some additional variables that influence the effect of ICT on business performance, such as various characteristics of the sectorial and the national context of the firm, new organizational practices, re-engineering of business processes, new human skills, etc.

2.3. ICT Investment Complements

In this direction during this second period considerable research has been conducted also in order to identify complementary actions and factors, which if combined with ICT investment, will maximise its contribution to business performance (usually referred to as 'ICT complements'). In this direction Black and Lynch (1997) examine the effect of ICT and new human resource management practices associated with total quality management, performance benchmarking and recruitment policies on productivity in USA manufacturing firms between 1987 and 1993. Their analysis indicates that these new human resource management practices make a positive contribution to productivity; also they found the investment in ICT and the usage of ICT by non-managers (e.g. workers) contribute positively to productivity. However, in this study the ICT investment and the above new human resource management practices are considered as separate independent variables, and their interaction and complementarity is not examined. Francalanci and Galal (1998), based on data from insurance companies, examine the effect of ICT investment, employees composition and the interaction between them on firm productivity; they conclude that increase in ICT spending combined with changes in employees composition (more 'information and knowledge workers') results in higher overall productivity. Devaraj and Kohli (2000) in their above-mentioned study concluded also that the combination of ICT investment with business processes reengineering increases the positive effect on output. Brynjolfsson et al. (2000) found that the combination of decentralisation practices (allocation of more decision authority, self managed teams, increase of worker responsibilities) with ICT has a disproportionately large positive effect on firm market value. Tallon et al. (2000), based on a survey of business executives, found that the strategic alignment of ICT investment with business strategy results in higher business value from the ICT investment; also they found that systematic post-implementation review and evaluation of the IS projects enhances the business value they generate. Ramirez (2003) investigated empirically the impact of ICT and three sets of organisational work practices: employee involvement, total quality management and reengineering; his results indicate that ICT is a key enabler of employee involvement and total quality management, and also that their combination with ICT contributes positively to the performance of firms. Brynjolfsson and Hitt (2000) review existing evidence on how ICT investments are linked to higher productivity and organizational transformation and conclude that '...both case studies and econometric work point to organisational complements, such as new business processes, new skills and new organisational and industry structures as a major driver of the contribution of information technology. These complementary investments, and the resulting assets, may be as much as an order of magnitude larger than the investments in the computer technology itself'. Arvanitis (2005), based on data from Swiss firms, constructed three composite indices for ICT capital, new organisational practices and human capital respectively, and examined their impact on labour productivity and their complementarity. His results indicate that ICT capital, new organisational practices and human capital all contribute positively to labour productivity, and also provide evidence of complementarity between ICT capital and human capital: the combined use of ICT and human capital results in additional labour productivity increase beyond the individual effects of these two factors. Hempell (2005), based on firm-level panel data from services firms covering a five years' period, concluded that ICT investments are closely linked to complementary innovations and at the same time they are more productive in firms with experience in innovations.

Melville et al. (2007) found that external environment factors also affect the productive impact of ICT capital. In particular, using data from publicly traded USA firms they found that the marginal product of ICT capital is lower in industries characterised by higher concentration, while the opposite happens with the traditional capital; also they did not find evidence that the marginal product of ICT capital is affected by the level of industry dynamism, but they found strong evidence that the marginal product of traditional capital is lower in industries with higher dynamism.

2.4. Gaps of previous research

One important gap of the previous research on the effect of ICT investment on business performance in both periods is that it has focused on the 'hard' ICT investment, namely on the investment in ICT hardware, software and networks; limited research has been conducted on the effect of the 'soft' ICT investment, defined as the investment in ICT human resources, skills and organization, on business performance, although it has been recognised in the relevant literature as an important 'soft complement' of the 'hard' ICT investment, which enables its effective exploitation and use in accordance with the needs and the strategy of the particular firm. The above-mentioned study of Brynjolfsson and Hitt (1996) examined directly the effect of one of the dimensions of the soft ICT investment, the ICT labour, on business performance; in their econometric models they included one ICT labour term and found that it has a positive statistically significant effect on the output and its marginal product is higher that the one of the non-ICT labour. Stratopoulos and Dehning (2000) dealt indirectly with the effect of some perspectives of the soft ICT investment on financial performance. From an empirical investigation using a matched pair approach they concluded that it is not only the ICT investment, but it is the 'successful' use and management of ICT inputs that improves financial performance. They reached this conclusion by comparing several measures of financial performance of 100 companies, which have been selected as being 'successful users' of ICT-based on four criteria-dimensions (percentage of revenue spent on ICT, suitability of IS for meeting business needs, evaluation of effectiveness of ICT use and profitability growth rate, with the financial performances of 100 similar companies, which are 'less successful users' of ICT; however, they do not examine separately the effect of each of the above four criteria-dimensions (and especially of each of the two criteria-dimensions which are associated with the soft ICT investment: the 'evaluation of effectiveness of ICT use' and the 'suitability of IS for meeting business needs') on financial performance. Bharadwaj (2000) also dealt indirectly with the effect of some perspectives of the soft ICT investment on a variety of profit and cost-based performance measures. Adopting a resource-based perspective and using a matched pair approach, he found that superior 'ICT resources', which consist of 'ICT physical infrastructure', 'human ICT resources' (technical and managerial ICT skills) and 'ICT-enabled intangibles' (knowledge assets, customer orientation, synergy between organizational divisions), result in superior performance in these performance measures; however, he does not examine the effect of each of these three components of the 'ICT resources' of a firm (e.g. of the 'human ICT resources') separately on business performance. Therefore further research is required concerning the effect of both the 'hard' investment and the 'soft' ICT investment (appropriately measured, so that all its dimensions are taken into account) on business performance, based on theoretically sound and complete models. From a quantitative study conducted in the Greek industry it has been found that this soft dimension of ICT investment is often neglected by the Greek industrial firms (Sirigos, 2001), and we believe that this might happen, at least to some extent, also in other similar national contexts.

Also, most of the research on the effect of ICT investment on business performance in both these periods has been based mainly on empirical studies conducted in the context of a few countries, which are characterised by high levels of economic development and ICT penetration, and also on data from large firms; so the conclusions of this research are conditional on the characteristics of these particular national contexts. OECD warns that the impact of ICT investment can differ significantly across countries, due to differences in 'the regulatory framework, the availability of appropriate skills, the ability to change organisational set-ups as well as the strength of accompanying innovations in ICT applications' (OECD, 2003). Also in a more recent report of OECD on the same subject it is argued that 'ICT is a network technology; the more people and firms that use the network, the more benefits it generates', therefore, taking into account that a few highly developed countries have the highest rates of ICT uptake, 'it is likely that the largest economic impacts of ICT should also be found in these countries' (OECD, 2004). Therefore it is necessary to investigate the effect of ICT investment on business performance also in other national contexts of countries, which are characterised by different levels of economic development, ICT diffusion and ICT skills, and also by different sizes of firms, legal frameworks and business culture.

3. Research hypotheses, method and data

Taking into account the above research gaps, the first objective of this study is to examine the effect of hard ICT investment (i.e. investment in ICT hardware, software and networks) on business performance in the Greek industry. The firm output (total sales revenue) has been selected as the basic business performance measure and dependent variable. This measure is directly related to the production function: the production function (F) relates the firm output (Q) to firm inputs X_i i, 1,..,n: $Q = F(X_1, X_2, \ldots, X_n)$ (Nicholson, 2004). In most empirical studies, including those of the published literature on the productive impact of ICT investments, the specification of the production function that has been used is that of the so-called Cobb–Douglas form (e.g. Linchtenberg, 1995; Brynjolfsson and Hitt, 1996; Gurbaxani et al., 1998):

$$Q = A \cdot X_1^{\alpha_1} \cdot X_2^{\alpha_2} \cdot \ldots \cdot X_n^{\alpha_n} \tag{1}$$

This form of the production function has certain advantages; for example it is homogeneous and also it is linear, for constant returns to scale (i.e. if $\alpha_1 + \alpha_2 + \ldots + \alpha_n = 1$). In its simplest version for $n = 2$, X_1 = capital (C), and X_2 = labour (L). However, as far as microeconomics is concerned, with such a specification, there are certain limitations:

(i) the marginal products $\left(\frac{\partial Q}{\partial X_i}\right)$ fall from the beginning;
(ii) the elasticities are necessarily constant;
(iii) the elasticities of substitution between X_i, X_j are constant and equal to 1.

For these reasons it is useful to investigate whether a more general form of a production function would be more appropriate for addressing the above research questions in the Greek national context, fitting better to our data than the Cobb–Douglas production function. Among the several generalizations of the Cobb–Douglas form (see for instance Intriligator et al., 1995) we selected to examine the so-called transcendental production function (TPF), which has more practical application in other types of studies than the other generalizations. For the case of the two basic inputs, labour and capital, the transcendental production function is defined as follows:

$$Q = A \cdot L^{\alpha_1} \cdot K^{\alpha_2} e^{(\alpha_3 L + \alpha_4 K)} \tag{2}$$

where X_1 = labour (L) and X_2 = capital (K).

Therefore we tested the following null hypotheses:

$H_0^{(1)}$: The function relating the output to the factors of production is of the Cobb–Douglas form, against the specific alternative of the transcendental form.
$H_0^{(2)}$: ICT hard investment makes no contribution to firm output.

In order to avoid problems associated with non-linear estimation, we assume that the stochastic disturbances enter into the Cobb Douglass and the transcendental production function equations in the following way:

$$Q = A \cdot L^{\alpha_1} \cdot K^{\alpha_2} e^{u_1} \tag{1'}$$

$$Q = A \cdot L^{\alpha_1} \cdot K^{\alpha_2} e^{(\alpha_3 L + \alpha_4 K)} e^{u_2} \tag{2'}$$

with u_1, u_2 obeying the conditions of the Gauss–Markov theorem. Then log-transforming (1′) and (2′) we have:

$$\log(Q) = \log(A) + \alpha_1 \log(L) + \alpha_2 \log(K) + u_1 \tag{1''}$$

$$\log(Q) = \log(A) + \alpha_1 \log(L) + \alpha_2 \log(K) + \alpha_3 L + \alpha_4 K + u_2 \tag{2''}$$

These equations are both linear and can be estimated by Ordinary Least Squares (OLS).

In this study, the capital input is broken down into two components: one related exclusively to ICT, referred to as computer capital (CK), and one for the rest of the capital input, referred to as non-computer capital or simply capital (K). Such a separation has been successfully used in the past in many relevant studies of the business impact of ICT investments on firm output (e.g. see Brynjolfsson and Hitt 1996; OECD 2003, 2004; Melville et al., 2004).

The above model, and in general all the econometric models to be estimated in this study, will be single equation linear models of the form: $\vec{Y} = X\vec{\beta} + \vec{U}$ where $\vec{Y}$ is a (NX1) vector of the observations of the dependent variable, X is a (NXK) matrix of the observations of the independent variables, $\vec{\beta}$ is a (KX1) vector of model parameters and $\vec{U}$ is a (NX1) vector of stochastic disturbances.

In this framework the null of any test of hypothesis to be performed in this study regarding $\vec{\beta}$ may be stated in the following way:

$$H_0 : R\vec{\beta} = \vec{r} \tag{3}$$

where **R** is a (qXK) matrix of known constants (with $q < K$), which are related to the character of the linear equations hypothesized between the model parameters (usually referred to as 'linear restrictions'), $\vec{r}$ is a (qX1) vector of known constants, and $\vec{\beta}$ is the (KX1) vector of model parameters. For the purposes of this work the test statistic used for $H_0 : R\vec{\beta} = \vec{r}$ is the one proposed by the relevant econometric literature (Johnston and Dinardo, 1997; Gujarati, 2003):

$$F = \frac{\frac{(\hat{U}'_R \hat{U}_R - \hat{U}'_{UR} \hat{U}_{UR})}{q}}{\frac{\hat{U}'_{UR} \hat{U}_{UR}}{(N-K)}} \tag{4}$$

where $\hat{U}_{UR},\ \hat{U}_R$ are the observed residuals of the so-called unrestricted regression model (i.e. the initial regression model without any linear restrictions) and restricted regression model (i.e. the regression model with the linear restrictions, the validity of which is to be tested) respectively, q is the number of linear restrictions, K is the number of estimated parameters in the unrestricted model and primes denote transposition. This statistic follows the F distribution with q, (N–K) degrees of freedom. The above statistic can be equivalently expressed in terms of the corresponding coefficients of determination (R^2_{UR} and R^2_R respectively) as:

$$F = [(R^2_{UR} - R^2_R)/q]/[(1 - R^2_{UR})/(N - K)] \tag{5}$$

Within this framework we can test any linear restrictions between the model parameters, including the particular form of the production function (i.e. Cobb–Douglas or transcendental).

Another objective of this study is to examine whether the 'soft ICT investment' in ICT human resources, skills and organization makes a positive contribution to the firm output, and to compare this contribution with the ones of the hard ICT investment, the labour and the 'non-ICT' investment. The soft ICT investment constitutes a very important complement of the hard ICT investment. It enables the formulation of the optimal composition of the hard ICT investment, namely the definition of the appropriate IS that should be developed, and also of the exact technical and functional requirements they should fulfil, based on the needs and the strategy of the particular firm, so that the value that will be generated by them for the firm will be maximized. Also it enables a better monitoring and management of the corresponding development projects, so that higher quality IS can be developed through them, and more benefits can be generated for the firm. Finally it enables a more efficient use and management of these IS once they have become operational. Moreover, the soft ICT investment is vital for designing and implementing the appropriate firm-specific ICT-based process and product innovations, and also the complementary 'co-investments', mentioned above in Section 2.3, in creating new organizational practices and human skills, re-engineering business processes, etc., which enable a higher degree of exploitation of the capabilities and the potential of ICT, and finally a higher level of business value from the hard ICT investment. Furthermore, since ICT hardware, packaged software and networks are available to competitors as well, they cannot provide a sustainable competitive advantage; it is only their combination with other resources and capabilities of the firm that can result in more sustainable competitive advantages, which necessitates both hard and soft ICT investments. In this direction Powell and Dent-Micallef (1997) from an empirical study in the retail industry found that ICT alone cannot provide sustainable performance advantages, but such advantages can be gained only by using ICT for leveraging intangible, complementary human and business resources of the firm. Also Mata et al. (1995), adopting a resource-based view of the firm, examine four basic attributes of ICT in a firm as to whether they can provide a sustainable competitive advantage: proprietary technologies, capital requirements, technical ICT skills and managerial ICT skills; they conclude that only the managerial ICT skills (defined as the ability of ICT management to understand the business needs of other functional units, customers and suppliers, and in cooperation with them to develop IS that cover these needs) can provide sustainable competitive advantage. For the above reasons the soft ICT investment is necessary for achieving a high level of benefits from the hard ICT investment, so we expect that it is likely to make a positive contribution to the firm output.

The soft ICT investment is by nature multidimensional, so it is highly important to define an appropriate framework for operationalizing and measuring it. After a review of the relevant literature we selected for this purpose the one of the well-established and widely cited Galliers's model of the 'stages of ICT growth' (Galliers and Sutherland, 1991), which has been extensively used, both in research and consulting, for the multidimensional assessment of the level of growth and maturity of an organization with respect to the use and management of ICT. For this purpose it uses 7 basic criteria-dimensions, usually referred to as the '7 s': strategy (=plan of related actions), (organizational) structure, systems (=formal and informal procedures), staff, skills, style (= culture and behaviour) and superordinate goals. In this preliminary study we have focused on three of these dimensions, which we regard as the most important components of the soft investment of a firm in ICT: ICT structure, ICT staff and ICT skills. For measuring these three dimensions we formulated the corresponding three variables: (i) the existence (or not) of a separate ICT department in the firm, which does not belong to any of the other departments of the firm (e.g. to the sales or the financial depertment) (ICT-DEP: binary variable measuring ICT structure), (ii) the number of ICT employees (ICT-EMPL: integer variable measuring the ICT staff of the firm) and (iii) the extent of ICT training provided to the users (ICT-TR: ordinal variable measuring the extent of ICT training provided to the employees of the firm who use its IS in a scale 1–5). Therefore we tested the following null hypotheses:

$H_0^{(3)}$: The existence of a separate ICT department in the firm makes no contribution to firm output.
$H_0^{(4)}$: The number of ICT employees of the firm makes no contribution to firm output.
$H_0^{(5)}$: The extent of ICT training provided to the users makes no contribution to firm output.

Also we examined whether there is complementarity between the hard ICT investment and each of the above three measures of the soft ICT investment with respect to firm output; in this direction we tested the following hypotheses:

$H_0^{(6)}$: There is no complementarity between the hard ICT capital and the existence of a separate ICT department with respect to firm output.
$H_0^{(7)}$: There is no complementarity between the hard ICT capital and the number of ICT employees with respect to firm output.
$H_0^{(8)}$: There is no complementarity between the hard ICT capital and the extent of ICT training provided to the users with respect to firm output.

For testing hypotheses $H_0^{(3)} - H_0^{(8)}$ the econometric model shown in Eq. (8) of the next Section 4 has been estimated, which includes a number of additional independent variables that correspond to the above three measures of soft ICT investment and also product terms of complementarity between them and the computer capital.

Finally another issue that has been examined in this study is the possible effect of the firm size on the structural stability of the constructed econometric models and therefore on the validity of the conclusions drawn from them. To this end initially the data have been sorted according to firm size (based on sales revenue) and then the so-called 'recursive residuals' (i.e. the one step ahead prediction errors) e_i, $i = 1 \ldots N$, where $N =$ the number of items of the sample, as well as their corresponding standard errors have been estimated. In particular, each recursive residual e_i has been estimated as the difference between the predicted value of the dependent variable of the i-th item of the sample, based on the econometric model that has been estimated from the previous i-1 items, minus the corresponding observed value of the dependent variable of this i-th item. The above recursive residuals are plotted together with the lines indicating their 95% confidence intervals, which correspond to plus and minus twice their recursively estimated standard errors. Residuals that lay outside these two standard error bands are indicative of structural instability. Such instabilities can be further investigated by estimating recursively the model parameters and their confidence intervals. In this way a sequence of the vectors of the estimated parameters can be created. Then a visual inspection of a plot showing the evolution of each model parameter together with the corresponding confidence interval (i.e. estimated value plus/minus two standard errors lines) can reveal cases of parameter instability separately for each parameter of the model. In the plot such instabilities will be reflected by vertical 'movements' to a level outside previous confidence bounds. Within the framework stated above, which is described in more detail in by Johnston and Dinardo (1997), we tested the following null hypothesis:

$H_0^{(9)}$: Firm size does not affect the structural stability of the constructed econometric models.

Since the data required for constructing the above-mentioned econometric models were not available in Greece (mainly concerning the hard and soft ICT investment of Greek firms), we collected for first time in Greece such a dataset, through a survey among Greek industrial firms in cooperation with the Federation of Greek Industries (FGI) (http://www.sev.org.gr/online/index.aspx). For this purpose a survey questionnaire was designed, which, amongst others, included questions concerning the yearly sales revenue, the computer capital (including hardware, software and networks), the non-computer capital and the yearly labour expenses of the firm; also it included questions measuring the above-mentioned three aspects of soft ICT investment: the existence or not of a separate ICT department in the firm, the number of ICT employees and the extent of ICT training provided to the users. The FGI selected the 250 biggest firms among its members, sent to them by mail the above questionnaire accompanied by a cover letter explaining them the objectives of this survey, and then contacted them by phone in order to inform them orally about the survey. The recipients were asked to fill in the questionnaire and return it by fax or mail within one month. After one month were contacted by phone once again all the recipients who had not responded. Finally were received filled questionnaires from 137 firms. The respondents were big firms for the Greek context: their average sales revenue for the year 2002 was *about* €68 million, ranking between €10 thousands and €1.5 billion, and most of them are listed at the Athens Stock Exchange (ASE); however they were much smaller than the big firms that most studies on this subject (e.g. in USA or other highly developed countries) were based on. In order to examine whether there is non-response bias we compared variables' means of the early respondents with the ones of the late respondents; this approach is a good alternative to the desirable approach of gathering data from a random sample of non-respondents and comparing them with the corresponding data provided by the respondents through the questionnaires they filled, since the latter approach is very often not feasible (Chapman, 1992; Dooley and Linder, 2003). No statistically significant differences have been found between the early and the late respondents concerning the means of all the variables used in this study, we can conclude that non-response bias does not exist.

4. Results

Initially we calculated the average yearly ICT spending of the respondent firms and we found it to be at the level of 1.2% of yearly sales revenue; it is lower than in the highly developed countries, where ICT spending has been reported to be at the level of 2–3% (depending on the industry) of sales revenue (e.g. see Robson, 1997). A possible explanation of this lower ICT spending by Greek firms is that the competition they face, even though it has increased since the entry of Greece in the European Union, is not as high as the competition faced by the firms in the highly developed countries. Therefore the market pressure on the Greek firms for more ICT investment and use is lower than in the highly developed countries; however, due to the growing globalisation of economic activity, the competition faced by the Greek firms is expected to increase in the near future, therefore it is highly likely that there will be more market pressure on them for more ICT investment and usage. Another possible explanation of this lower ICT spending by Greek firms is their smaller size, which results in a lower level of economies of scale in using high fixed cost ICT capital and specialised labour.

In order to test $H_0^{(1)}$ the following models were estimated:

$$\log(Q) = \alpha_0 + \alpha_1 \log(L) + \alpha_2 \log(K) + \alpha_3 \log(CK) + u_1(\text{restricted model}) \tag{6}$$

$$\log(Q) = \beta_0 + \beta_1 \log(L) + \beta_2 \log(K) + \beta_3 \log(CK) + \beta_4 L + \beta_5 K + \beta_6 CK + u_2(\text{unrestricted model}) \tag{7}$$

The estimation results, as well as the coefficients of determination R-squared, are shown in Table 1:

Using the above results the value of the F-statistic of Eq. (5) has been calculated:

$$F = [(R_{UR}^2 - R_R^2)/q]/[(1 - R_{UR}^2)/(N\text{–}K)] = 2.74 \tag{8}$$

where R_{UR}^2 and R_R^2 are the coefficients of determination of the unrestricted and the restricted model respectively, q is the number of linear restrictions, K is the number of estimated parameters in the unrestricted model and N is the sample size, while the corresponding critical F-value at the 0.05 significance level is 2.76. From the above results we can see that two of the additional coefficients included in the unrestricted model, those of the computer capital (CK) and the non-computer capital (K), are clearly insignificant, while the third additional coefficient, that of the labour (L), is only marginally significant at the 5% level (its very small value can be justified taking into account that it corresponds to a non log-transformed variable, in contrast with the first three coefficients of this unrestricted model, which are much bigger since they correspond to log-transformed variables). Also, we remark that the above calculated F-value is slightly less than the critical one, which means that the improvement in the explanatory power of the more complicated unrestricted model is only marginal as compared to that of the restricted model, which has a much simpler form. This means that the production process can be adequately described by the Cobb–Douglas production function, hence, the null hypothesis $H_0^{(1)}$ is not rejected. It is noted that although in the models estimated above the capital input is broken down to computer capital (CK) and non-computer capital (K), the conclusion is the same if total capital is used instead of K and CK.

Concerning hypothesis $H_0^{(2)}$, from the above results it is also evident that the coefficient of computer capital is positive and statistically significant, therefore it makes a positive contribution to firm output, which means that hypothesis $H_0^{(2)}$ is rejected. By comparing the coefficients of the restricted model of Table 1, which are estimates of output elasticities of the corresponding inputs, we remark that the output elasticity of labour (0.732) is approximately ten times higher than the output elasticity of computer capital (0.078) and more than four times higher than the output elasticity of non-computer capital (0.184). That underlines the dominant

Table 1
Results of estimation of the restricted and unrestricted models for Hypothesis $H_0^{(1)}$

Dependent variable: ln Q Independent variable	Coefficient	Significance
Unrestricted model		
Constant	1.481	0.028
ln (CK)	0.108	0.001
ln (K)	0.176	0.000
ln (L)	0.671	0.000
CK	−5.237E−11	0.920
K	1.305E−13	0.933
L	1.393E−12	0.050
R-squared: 0.942		
Restricted model		
Constant	0.573	0.186
ln (CK)	0.078	0.001
ln (K)	0.184	0.000
ln (L)	0.732	0.000
R-squared: 0.935		

role of the labour input in the big Greek industrial firms, the lower role of the non-computer capital and the much lower role of the computer capital. Summarizing, it is concluded the hard ICT investment has a positive statistically significant effect on firm output, however its output elasticity is lower than the one of the non-computer capital and much lower than the one of labour.

In order to test hypotheses $H_0^{(3)} - H_0^{(8)}$ the following general model form has been used:

$$Q = \prod X_i^{a_i} e^{\left(\sum b_i z_i + \sum\sum c_{ij} X_i Z_j + U\right)} \tag{9}$$

where X_i represent the basic inputs (labour, non-computer capital and computer capital in our case), Z_i represent the variables relating to the soft ICT investment and the product terms X_iZ_i represent complementarities between the soft ICT investment variables and the basic inputs. As described and justified in the previous Section 3 the soft ICT investment variables considered in this study are the existence (or not) of a separate ICT department in the firm (ICT-DEP), the number of ICT employees (ICT-EMPL) and the extent of ICT training provided to the users (ICT-TR); since the third variable is ordinal and has five levels, it will be represented in the model by the four binary variables ICT-TR1, ICT-TR2, ICT-TR3, ICT-TR4 (each of them takes value 1 for one of the four higher levels of IC-TR, and value 0 in any other case). Additionally, the products of these six variables to the computer capital are used to express the possible effects of complementarity between these dimensions of the soft ICT investment and the hard ICT investment. So by log-transforming (8) we formulated a linear model similar to the one of Eq. (6), but including twelve additional independent variables: the above six soft ICT investment variables and also the product terms of complementarity between them and the computer capital. The results of the estimation of this model are shown in Table 2. Using these results the value of the F-statistic has been calculated:

$$F = [(R_{UR}^2 - R_R^2)/q]/[(1 - R_{UR}^2)/N - K] = 1.96 \tag{10}$$

where R_{UR}^2 and R_R^2 are the coefficients of determination of the unrestricted model shown in the above Table 2 and the restricted model shown in the lower part of Table 1 respectively, q is the number of linear restrictions, K is the number of estimated parameters in the unrestricted model and N is the sample size; since the corresponding critical F-value at the 0.05 significance level is 1.99, this means that the overall effect of soft ICT investment variables and complementarities between them and the computer capital is not significant. However, from the above results it is evident that, though the existence of a separate ICT department in the firm makes a statistically significant positive contribution to firm output, the effect of the number of ICT employees and the extents of ICT training is clearly not statistically significant. Additionally there is no statistically sig-

Table 2
Results of estimation of the model of Eq. (8) for testing hypotheses $H_0^{(3)} - H_0^{(8)}$

Dependent variable: ln Q Independent variable	Coefficient	Significance
Constant	1.725	0.067
ln (CK)	0.030	0.040
ln (K)	0.166	0.000
ln (L)	0.736	0.000
ICT-DEP	0.205	0.034
ICT-EMPL	0.003	0.610
ICT-TR1	0.064	0.791
ICT-TR2	0.013	0.954
ICT-TR3	0.102	0.667
ICT-TR4	0.034	0.898
CK* ICT-DEP	−6.70E−010	0.658
CK* ICT-EMPL	1.77E−011	0.652
CK* ICT-TR1	1.05E−009	0.615
CK* ICT-TR2	1.34E−009	0.467
CK* ICT-TR3	3.38E−010	0.881
CK* ICT-TR4	2.21E−009	0.438
R-squared: 0.951		

nificant effect of the interaction between the computer capital and any of the soft ICT investment variables. We must note, however, that the conclusion concerning the interaction between ICT-DEP and computer capital may be a result of high correlation between the variables ln(CK) and ICT-DEP.

Excluding from the model the above non-significant explanatory variables and in this way allowing for more degrees of freedom a more efficient estimation of model parameters may be obtained; the results are shown in Table 3. Using the above results the value of the *F*-statistic is:

$$F = [(R^2_{\mathrm{UR}} - R^2_{\mathrm{R}})/q]/[(1 - R^2_{\mathrm{UR}})/N - \mathrm{K}] = 5.75 \tag{11}$$

while the corresponding critical value at the 0.05 significance level is 4, therefore we can reject the hypothesis $H_0^{(3)}$, which confirms that the effect of having a separate ICT department in the firm is significant, as is (equivalently) indicated by the *t*-statistic of the corresponding parameter estimate. Summarizing, the above results do not provide evidence for rejecting hypotheses $H_0^{(4)} - H_0^{(8)}$, but provide evidence for rejecting hypothesis $H_0^{(3)}$; so it is concluded that from the three investigated measures of the soft ICT investment, the creation of a structure for managing ICT in the firm, a separate ICT department that does not belong to any of the other departments of the firm, such as the sales or the financial department, has a positive statistically significant effect on firm output. It is also interesting to compare the effect of this dimension of the soft ICT investment on output with the effect of the hard ICT investment and also with the effects of the two basic production inputs: the labour and the 'non-ICT' investment. For this purpose we have used the standardized coefficients of the independent variables of the model of Table 3, which are shown in the third column, next to the unstandardized coefficients. From them we can see that the effect of having a separate ICT department in the firm on output is lower than the effects of the other three production inputs (labour, non-computer capital and com-

Table 3
Results of estimation of the model of Eq. (8) excluding non-significant variables

Independent variable: ln (*Q*)	Coefficient	Standardized coefficient	Significance
Constant	1.001		0.034
ln (CK)	0.061	0.062	0.013
ln (*K*)	0.177	0.179	0.000
ln (LT)	0.732	0.787	0.000
ICT-DEP	0.144	0.042	0.032
R-squared: 0.940			

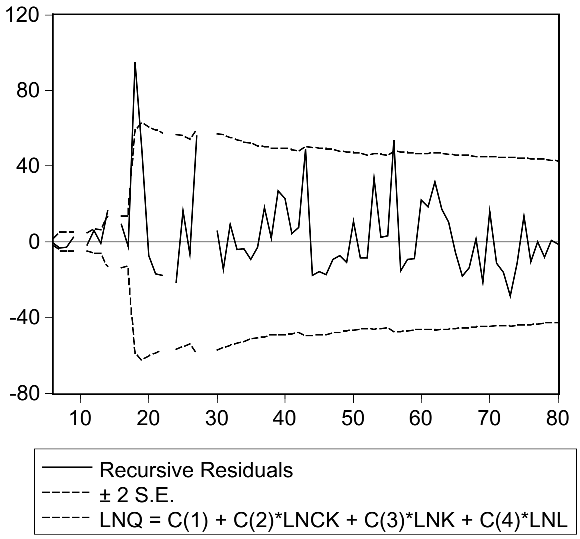

Fig. 1. Recursive residuals and their 95% confidence band.

puter capital), however it is at a considerable level of 0.042/0.062 = 68% (about two thirds) of the effect of the hard ICT investment. This finding underlines the importance of this dimension of the soft ICT investment, as it can increase by two thirds on average the business value generated by hard ICT investment.

Finally we tested hypothesis $H_0^{(9)}$ which relates to the possibility of a size-of-firm effect on the structure of the estimated econometric models. Initially the recursive residuals have been estimated together with their 95% (i.e. plus/minus two standard errors) confidence band for our 'basic' model:

$$\log(Q) = \beta_0 + \beta_1 \log(L) + \beta_2 \log(K) + \beta_3 \log(CK) + u \qquad (12)$$

following the procedure described in the previous Section 3. Fig. 1 shows the estimated recursive residuals and the above confidence band:

From Fig. 1 it can be seen that after some instability, up to the sample size of about 20 (which can be attributed to the small sample size the corresponding models and residuals are based on), the recursive residuals remain within the confidence band with two exceptions of rather minor character at sample sizes of 42 (corresponding to sales of about €43 million) and 56 (corresponding to sales of about €74 million). In order to investigate whether this may be attributed to a particular coefficient of the model, as mentioned in the previous Section 4, the parameters of the model were estimated recursively; these recursive parameter estimates, together with their 95% confidence band are shown in Fig. 2. From the two upper plots of this Figure it is

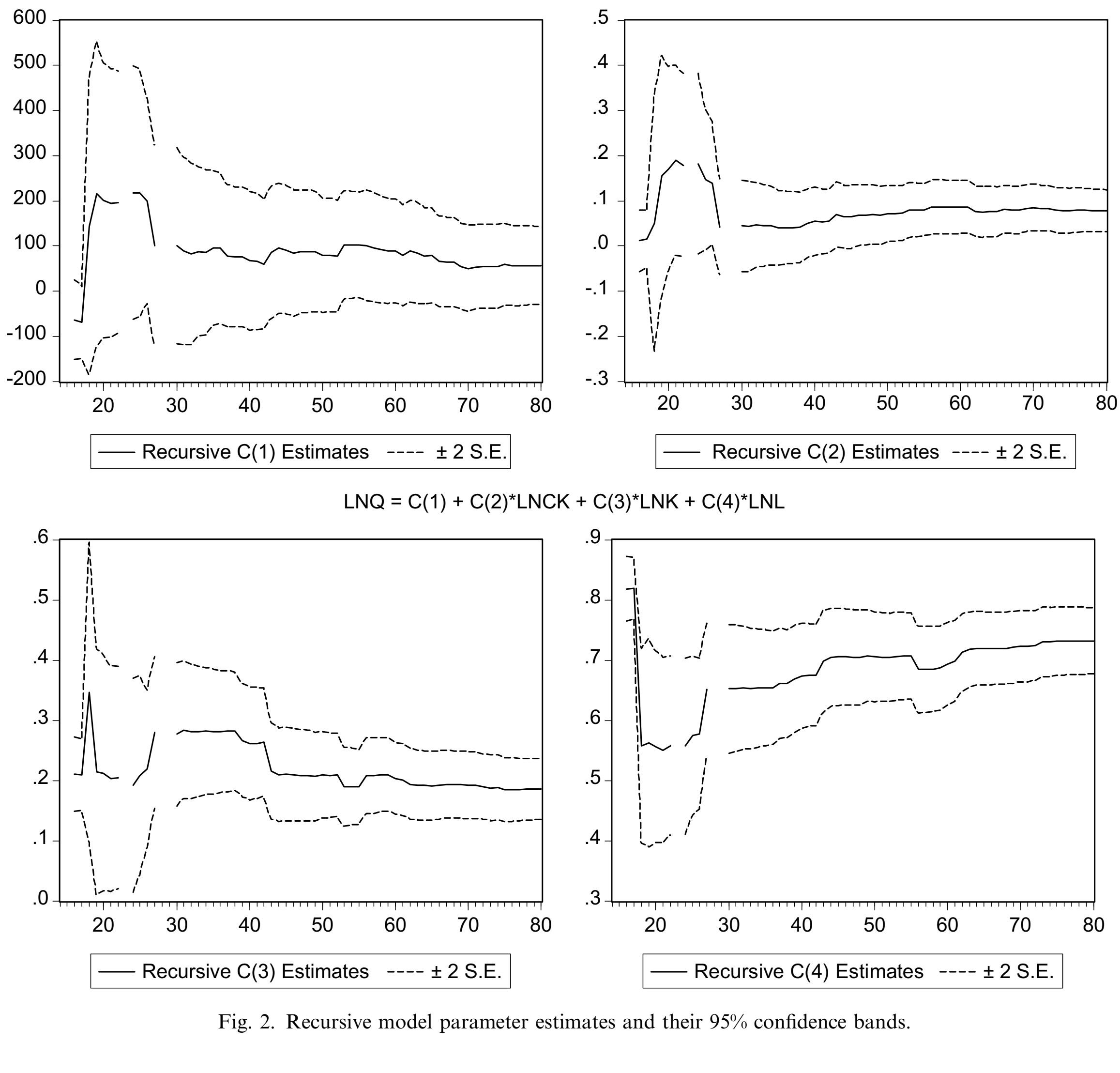

Fig. 2. Recursive model parameter estimates and their 95% confidence bands.

evident that after a sample size of about 30 (corresponding to sales of about €30 million) the constant as well as the coefficient of log(CK) are fairly stable. The estimates of the coefficient of log(K), as we can see from the left lower plot, shows a small vertical decline at sample size 42, and a small and temporal downward displacement at sample size 56. Finally the estimates of the coefficient of log(L), as we can see from the right lower plot, shows a very small increase at sample 42 and a temporal displacement at sample size 56. Hence, the instability at sample size 42, spotted in Fig. 1, can be attributed mainly to the coefficient of log(K), while the instability at sample size 56 may be attributed to both the coefficients of log(K) and log(L). However, as all these vertical displacements remain inside previous confidence bounds, these instabilities are of minor importance and, by and large, after a sample size of about 30, corresponding to an output of about €20 million, the models can be considered as being unaffected by the size of firms, for the range of firm sizes that our data cover. Therefore hypothesis $H^{(9)}$ cannot be rejected. Similar conclusions have been drawn for the other models that have been estimated in this study.

5. Summary and conclusions

In this paper the first econometric study of the effect of ICT investment on business performance in Greece is presented. It investigates the effect of both 'hard' ICT investment (i.e. investment in ICT hardware, software and networks) and 'soft' ICT investment (investment in ICT human resources, skills and organization) on firm output. It is based on data from big Greek industrial firms, which have been collected via a questionnaire-based survey conducted in cooperation with the Federation of Greek Industries (FGI). Initially it has been concluded that ICT spending by firms in Greece is lower than in the highly developed countries; the lower level of competition faced by the Greek firms, and also their smaller size (allowing a lower level of economies of scale), in comparison with the firms of the highly developed countries, are possible explanations. The hypothesis that the function relating the output to the factors of production (inputs) in the context of the Greek industry is of the Cobb–Douglas form is not rejected against the specific alternative of the more general transcendental form; therefore it is concluded that the production process in the Greek industry can be adequately described by the Cobb–Douglas production function, while the use of the more general transcendental form for this purpose does not improve the explanatory power of the models.

Then by estimating econometric models based on the Cobb–Douglas production function it has been found that the hard ICT investment has a positive statistically significant effect on firm output; however its output elasticity is lower than the one of the non-computer capital and much lower than the one of the labour. This is mainly due to the above-mentioned low level of ICT spending that characterises the Greek industries, which results in a low level of computerization of their functions. The results underline the dominant role of the labour input in the big Greek industrial firms, the lower role of the non-computer capital and the much lower role of the computer capital.

Concerning the soft ICT investment, initially a framework has been developed for operationalizing and measuring it, so that its effect on firm output can be investigated; this framework is based on the well-established and widely used (both in research and consulting) Galliers's model of the 'stages of ICT growth', which proposes 7 basic dimensions. In this preliminary study we have focused on three of these dimensions, which we consider as the most important ones: ICT structure, ICT staff and ICT skills; we measured them through three corresponding variables: the existence (or not) of a separate ICT department in the firm, the number of ICT employees and the extent of ICT training provided to the users. From these three investigated measures of the soft ICT investment, based on econometric modelling, it has been found that the existence of a separate ICT department has a positive statistically significant effect on firm output, which is of a considerable magnitude of about two thirds of the effect of the hard ICT investment. This finding underlines the importance of this dimension of the soft ICT investment, as it can increase by two thirds on average the business value generated by the hard ICT investment.

Our last conclusion refers to the structural stability of the econometric models we constructed with respect to firm size (measured through sales revenue). Using a method based on the 'recursive residuals' it has been found that after a sample size of about 30, which corresponds to sales of approximately €20 million, the models structure can be considered as being unaffected by the size of firms, for the range of firm sizes that our data cover. This means that the conclusions drawn from these models are not affected by firm size.

The above conclusions enable a better understanding of the impact of both hard and soft ICT investment on business performance in a national context different from the ones of the highly developed countries. We believe that the conclusions of this study may be related, at least to some extent, to the Greek national context, which has a number of particular characteristics mentioned briefly in the introduction. Greece has made considerable economic progress in the last decade and has become a member of the European Economic and Monetary Union. Since most of the firms of the sample used in this study, as mentioned in Section 3, are listed at the Athens Stock Exchange (ASE), it should also be mentioned that several changes have occurred during the 90's in the legislative and regulatory framework regarding ASE and the listed firms towards harmonization with international standards (for details see for instance Alexakis and Xanthakis, 1995; Laopodis, 2004 and the forthcoming paper of Kenourgios et al. (forthcoming)); as a result of these changes in May 2001 Morgan Stanley Capital International upgraded ASE to a developed market status, while previously ASE belonged to the so-called European Emerging Markets. However, despite these reforms, the Greek firms have still some idiosyncratic characteristics, mainly related to corporate governance, that are noteworthy, as they are not usually found in firms listed in other developed financial markets: in many firms, even in big ones, the majority of company ownership belongs to members of the same extended family; also in many firms there is no distinction between ownership and management with big shareholders being also the members of the board of directors. Furthermore, Greece is characterised by smaller average firm size, smaller size of internal market, lower intensity of competition and lower level of ICT usage, and also limited history and experience in this domain, in comparison with the highly developed countries ('Digital Strategy 2006–2013', 2005). The above characteristics of the Greek national context affect negatively the capability of Greek firms to manage their hard and soft ICT investments and generate business value from them. For this reason we believe some of the conclusions of this study, e.g. the fact that we identified only one of the investigated soft ICT investment variables (existence of a separate ICT department), and none of their products with the 'hard' computer capital (interaction-complementarity terms), as statistically significant, or the lower level of output elasticity of the computer capital we found, in comparison with the non-computer capital and the labour, may be related, at least to some extent, to these Greek national context characteristics. In that respect it would be of interest to apply the econometric analysis performed in this study in order to examine the effect of the explanatory variables considered here on firm output in other national contexts and compare the results.

Further research is in progress by the authors concerning the impact of ICT hard and soft investment on various business performance measures in Greece, based on a bigger sample and examining a wider set of soft ICT investment dimensions (including all the dimensions proposed by Galliers's model of the 'stages of ICT growth'); also is being examined whether there is complementarity between ICT hard and soft investment on one hand, and new work practices and business processes, total quality, and reorganization on the other.

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