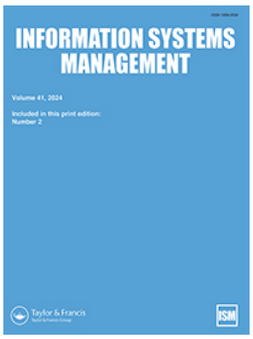

Information Systems Management

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/uism20

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To cite this article: Sp. Arvanitis & E. Loukis (2024) Factors Explaining ICT Investment Behavior of Firms During the 2008 Economic Crisis, Information Systems Management, 41:2, 110-131, DOI: 10.1080/10580530.2023.2213839

To link to this article: https://doi.org/10.1080/10580530.2023.2213839

Published online: 24 May 2023.

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INFORMATION SYSTEMS MANAGEMENT
2024, VOL. 41, NO. 2, 110–131
https://doi.org/10.1080/10580530.2023.2213839

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Factors Explaining ICT Investment Behavior of Firms During the 2008 Economic Crisis

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ABSTRACT
In this paper, we develop a set of research hypotheses concerning the effects of six groups of factors on firms' behavior during the 2008 global economic crisis with respect to ICT investment: three groups of internal factors (overall firm resource endowment, ICT-related resource endowment, ICT-related capabilities) and three groups of factors (competition, liquidity problems, macroeconomic conditions concerning demand). These research hypotheses are tested using data from Greek firms for the economic crisis period 2009–2014.

KEYWORDS
ICT; ICT investment; ICT resources; ICT capabilities; Cloud computing; economic crisis

Introduction

Economic crises of different intensities and durations are repeatedly appearing in market economies and constitute severe "shocks" in firms' external environment, with quite negative consequences. On one hand, for their production, employment and procurement, resulting in increase in unemployment, poverty and social exclusion; and, on the other hand, for firms' investment, resulting in technological backwardness and obsolescence, and finally impairing their future competitiveness and even threaten their survival (Allen, 2016; Bo et al., 2014; Fagerberg & Srholec, 2016; Knoop, 2010). Numerous economic crises of various origins have appeared in the last 100 years (Knoop, 2010); a decade ago we experienced the severe 2008 global economic crisis, which had quite negative consequences for economies and societies worldwide, while recently the COVID-19 gives rise to another economic crisis (Baldwin & DiMauro, 2020). However, the extent of these negative consequences of economic crises differs considerably among firms, so it is quite useful to identify factors that affect their magnitude (increasing or decreasing it) at firm-level, as this can provide a basis for developing effective crisis-resilience strategies, and in general for managing better the continuously appearing economic crises.

During the severe global economic crisis of 2008 there has been significant decrease in investment, and this definitely included ICT investment (OECD, 2009, 2010; Rojko et al., 2010). Firms reduced their ICT investment, though the extent of reduction differs considerably among firms, and this led to loss of opportunities for exploiting both traditional as well as emerging novel ICTs for efficiency improvement and innovation. According to the annual study of the key issues that firms' ICT executives face conducted by the USA Society for Information Management (SIM) in 2009 a main issue and challenge they face was the reduction of ICT budgets and salaries and the cancelations or redimensioning of important ICT projects, ICT purchases and ICT personnel hiring due to the global economic crisis (Luftman & Ben-Zvi, 2010).

According to economic theory, the expectation for the impact of economic crises on ICT investment is the same as for all other kinds of investment: firms' investment propensity decreases in periods of economic recession (see section 2.1 for more details). In particular, during such periods firms face decrease of demand for their products as well as uncertainty, which, on one hand, reduce the financial resources available for investment, and, on the other hand, make investment more risky than in "normal" or boom periods, leading to a *"pro-cyclical"* behavior of investment reduction. However, particularly in the innovation literature (Archibugi et al., 2013a; Arvanitis & Woerter, 2014), an alternative approach has been identified and analyzed that can lead to an *"anti-cyclical"* investment behavior. In particular, during economic crises, the costs of labor and other input factors required for R&D are lower in comparison with "normal" or

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booming periods (Rafferty & Funk, 2004), and at the same time "opportunity costs" are lower. So, firms might benefit if they shift resources to R&D activities, and this can lead to an increase in innovation-related investment. It is then an empirical issue to examine in various national and sectoral contexts which approach prevails for each particular investment type (pro-cyclical or anti-cyclical behavior), and which factors affect relevant investment behaviors of individual firms.

Some research has been conducted concerning the effects of 2008 crisis-induced reduction of external financing, mostly in the form of bank credit supply, on firms' investment in general (Duchin et al., 2010; Kahle & Stulz, 2013; Nguyen et al., 2015 for USA firms; Akbar et al., 2013 for UK firms; Zubair et al., 2020 for NL firms; Bo et al., 2014 for Chinese firms). Also, there are some studies investigating the effects of a limited range of factors on firms' innovation investments during the 2008 economic crisis (Archibugi et al., 2013b for European firms; Archibugi et al., 2013a for UK firms; Arvanitis & Woerter, 2014 for Swiss firms; Brem et al., 2020 for European firms, focusing on the development of innovative products that become "dominant designs"). However, there is a lack of research investigating the effects of various factors on firms' ICT investment during the crisis, despite the high importance of this particular kind of investment on firms' efficiency, innovation, and finally their competitiveness and even their survival, which makes the identification of such factors quite valuable for firms' resilience to, and even survival in, economic crises. Though IS research has traditionally shown much interest in investigating the impact of various aspects/elements of the external environment on the utilization and exploitation of ICT by firms (e.g., Chae et al., 2018; Melville et al., 2004, 2007), this has not been done for economic crises, though they constitute the most severe external environment shocks that firms repeatedly experience and have to bear and manage.

Therefore, it is quite interesting and useful to investigate the factors that explain firms' behavior during economic crisis with respect to ICT investment, and affect (positively or negatively) firms' relevant resilience to economic crises, given, on one hand, the importance of this kind of firms' investment for their efficiency, innovation, and finally their competitiveness and even their survival, and, on the other hand, the lack of studies concerning the impact of economic crisis on firms' ICT investment and the factors that affect it.[1] This research can contribute to a better understanding of the factors that affect firms' resilience to economic crisis with respect to ICT investment, and provide a basis for undertaking appropriate actions at firm-level in order to reduce the negative impact of economic crises on their investment in these highly important technologies. Given that ICT constitute a growth-determining factor of increasing importance (OECD, 2010) and that economic crises are an inevitable trait of market-based economies (Allen, 2016; Fagerberg & Srholec, 2016; Knoop, 2010), it is important for firms to know which factors could enable them to become more resilient to economic crisis, when the next one comes.[2] Gaining an understanding of the factors that weaken or strengthen the negative effects of the most severe "shocks" that appear in firms' external environment on their ICT investment is quite useful for individual ICT-using firms, and also for ICT-producing firms (ICT vendors), for consulting firms as well as for central or regional government agencies having economic development competencies, by providing them useful assistance for the development of strategies for managing future crises.

In this direction, our study, having as theoretical foundation the model of firm-level ICT utilization and exploitation developed in Melville et al. (2004), which is elaborated using the Resource-based View of the firm as well as economic crisis theories (see section 2), we develop and test a set of research hypotheses concerning the effects of six groups of factors on firms' ICT investment behavior during the 2008 economic crisis. Three of these groups refer to internal factors, namely overall firm resource endowment, ICT-related resource endowment, and ICT-related capabilities. Three further groups refer to external factors, namely competition conditions at a firm's product market, liquidity problems with respect to important transaction partners (customers, providers, banks), and macroeconomic conditions concerning the demand for firm's products and services. Based on related previous research literature, we have identified the specific variables of each group that might affect significantly ICT investment behavior during the crisis period 2009–2014. We empirically investigate the effects of these internal and external factors on firms' crisis vulnerability with respect to ICT investment, defined as the extent of the crisis-induced reduction of their ICT investment. To our knowledge, there is no other study investigating these topics, so our paper has also the character of an explorative study in a new and highly important for management practice research field.

The Greek economy has been strongly hurt by the 2008 global economic crisis (Gourinchas et al., 2016), particularly ICT investment expenditures (Loukis et al., 2017). The annual turnover of the ICT services sector, which can serve as indicator of firms' ICT activities, has decreased by about 40% in Greece between 2008 and 2014 (Eurostat, 2016). Therefore, the context of Greece is particularly appropriate for investigating the effects of a wide range

of internal and external factors on firms' ICT investment behavior during economic crisis. So, our study is based on Greek firm data from the manufacturing, construction, and services sector for the period 2009–2014.

The paper is structured as follows: section 2 presents the conceptual background and the research hypotheses of our study. Section 3 describes the data used in this study. Section 4 presents the specification of our models. In section 5 econometric issues and results are presented and discussed. Finally, section 6 concludes the paper.

Conceptual background and research hypotheses: economic crisis and ICT investment

Melville et al. (2004), based on a review of previous relevant information systems (IS) research, developed a model of firm-level ICT utilization and exploitation. According to this model three categories of factors determine and shape the utilization and exploitation of ICT in a firm: i) characteristics of the firm (e.g., technological and human ICT resources, as well as other complementary firm resources, such as human resources, workplace organization practices, etc.); ii) characteristics of its external sectoral environment (e.g., competition); iii) characteristics of its external macro-environment (at country level, e.g., economic growth, relevant regulation, etc.). Therefore, we can expect that a firm's ICT investment behavior in economic crisis is affected by these three categories of factors. For each of these categories we have identified based on previous research literature specific groups of factors that might affect ICT investment behavior in the crisis, and developed a series of research hypotheses, which are described in the following subsections 2.1 (for macro-environment factors), 2.2 (for firm-related factors) and 2.3 (for sectoral environmental factors). Our research model is shown in Figure 1.

Macro-environment factors

We are starting with two research hypotheses concerning the effects of two groups of macro-environment factors that, according to previous theoretical and empirical work on economic crises, constitute the main manifestations of economic crises: reduction of demand for

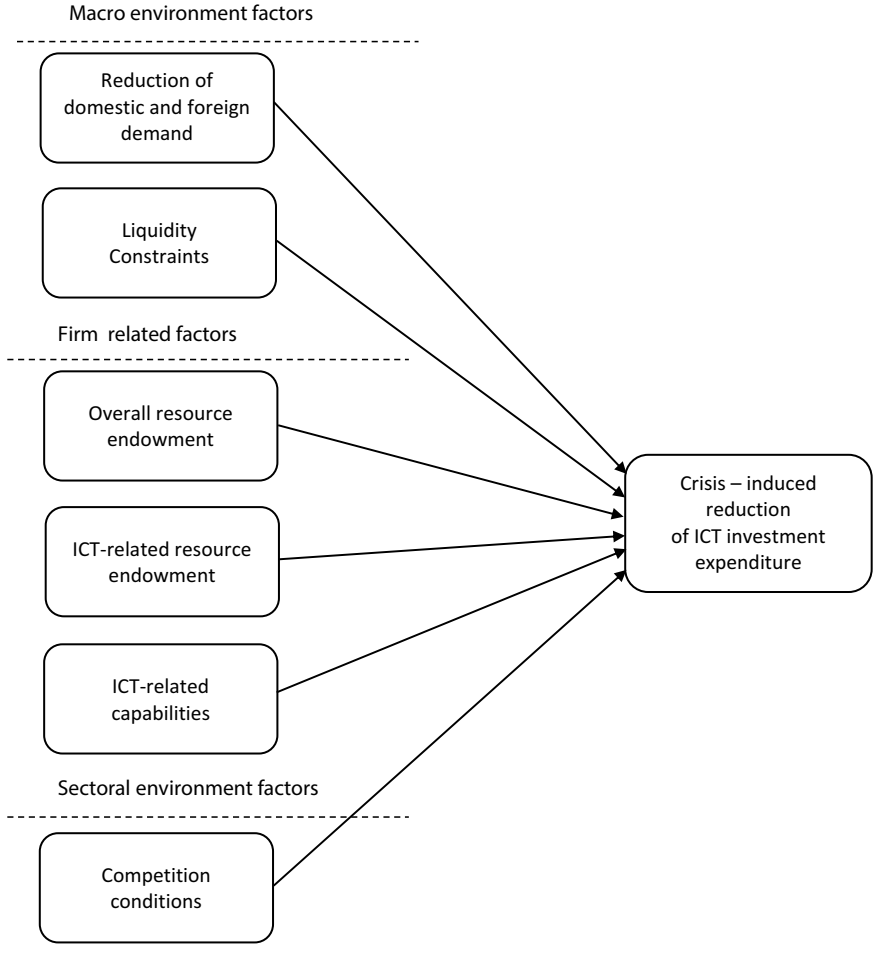

Figure 1. Research Model.

products/services and liquidity constraints. In particular, market-based economies show the tendency to periodical fluctuations of economic activities (business cycles: Fagerberg & Srholec, 2016; Knoop, 2010). Such fluctuations affect seriously investment in general, and particularly investment in R&D, innovation, and (adoption of) new technology (e.g., ICT). There are reasons for firms to react usually *pro-cyclically*, decreasing such investment in periods of economic recession (see below), though sometimes firms might react *anti-cyclically* (or *"neutral"*), thus maintaining or even increasing such investment (Archibugi et al., 2013b; Arvanitis & Woerter, 2014). Given the *cumulative character* of investment in innovation and new technology, pro-cyclical behavior causes technological backwardness and obsolescence as well as considerable losses of knowledge that cannot be easily compensated. So, understanding the motives of firms' anti-cyclical behavior would enable *policy* to try to promote and enhance such behavior, thus smoothening investment along time and in this way avoiding damaging fluctuations of it.

In particular, the general investment propensity of firms decreases in periods of economic recession, as firms are confronted with demand decrease and uncertainty that makes investment more risky than in "normal" or boom periods. Furthermore, decreasing demand limits also internal financing of investment by past revenues (Fagerberg & Srholec, 2016; Knoop, 2010); such liquidity constraints further reduce firms' space for investment (Hall et al., 1998; Hall, 1992; Himmelberg & Petersen, 1994). Uncertain economic perspectives reduce also the willingness of banks and other financial intermediaries to finance firms' investment projects, which further increases liquidity constraints. However, all kinds of investment do not bear the same risk, with innovation projects being considered as quite risky, and buildings being seen as much less risky than other investment categories (see, e.g., Kahle and Stulz, 2010; Gerner & Stegmaier, 2013; Geroski & Gregg, 1997). Further, all types of firms do not bear the same risk. Small firms are confronted with more difficulties to finance investments in recession than large firms, due to credit rationing, i.e. limited access to external funding by financial intermediaries (for the economics science fundamental theoretical background of the above see, e.g., Stiglitz & Weiss, 1981 for investment in general; Goodacre & Tonks, 1995 for investment in innovation).

However, there are also some theoretical arguments as well as some anecdotic evidence that firms show sometimes an anti-cyclical investment behavior mainly for R&D investment (Arvanitis & Woerter, 2014; Barlevy, 2007; F. Aghion & Saint-Paul, 1998; Rafferty & Funk, 2004). Costs for labor and other input factors (e.g., equipment) required for the generation of innovations are usually high in a booming phase and low in a recession phase. Furthermore, input factors are not fully used in recession times, thus the *opportunity costs* of an alternative use of these factors are lower than in boom times, and firms would benefit from a shift of them to innovation activities (given that *technological opportunities* are anticipated). When the economy improves, firms could launch new products and benefit from additional investment in innovation in the recession phase.

Consequently, in order to explain pro- or anti-cyclical ICT investment behavior we have to take into account the above two diverging forces, on one hand, the demand aspect and, on the other hand, the opportunity costs aspect (Rafferty & Funk, 2004). Since ICT investment is predominantly financed through the cash flow of a firm, which is expected to fluctuate pro-cyclically with demand, we would expect a pro-cyclical ICT investment behavior as well, with crisis-induced ICT investment reduction being positively correlated with the reduction of demand (domestic and foreign) caused by the economic crisis. Furthermore, difficulties in financing ICT investment, beyond the ones caused by this demand reduction, are also caused by liquidity constraints due to the behavior during the crisis of external players, such as banks and other financial intermediaries, suppliers, and customers. So, we expect that liquidity constraints caused by the crisis-induced decrease in credit limits by banks and by suppliers, as well as the decrease in paying willingness of customers due to the economic crisis, would be positively correlated with the crisis-induced reduction of ICT-related investment. Based on the above discussion we formulate the following two hypotheses:

Hypothesis 1: Reduction of domestic and foreign demand due to overall contraction of economic activities in the economic crisis correlates positively with crisis-induced reduction of ICT-related investment.

Hypothesis 2: Liquidity constraints at firm level (due to banks,' suppliers' and customers' behavior) in the economic crisis correlate positively with crisis-induced reduction of ICT-related investment.

Firm-related factors

As a starting point for the identification of relevant firm-level determinants of ICT investment behavior in crisis, we refer to the Resource-based View of the firm (Barney, 1991, 2001; Penrose, 1959; Wernerfelt, 1984).

According to this theoretical approach, critical determinants of a firm's performance are its resources (e.g., assets, human resources, etc.), as well as its capabilities for deploying and utilizing these resources in order to perform important tasks, so that performance differences among firms operating in the same environment are mainly created by differences among them with respect to available resources and capabilities.

Barney (1991) initially gave a wide definition of firm's resources as "all assets, capabilities, organizational processes, firm attributes, information, knowledge, etc. controlled by a firm that enable the firm to conceive of and implement strategies that improve its efficiency and effectiveness." Assets could be tangible (e.g., human resources, equipment, ICT hardware and software applications) or intangible (e.g., organizational routines or practices, know-how; see, e.g., Lev (2001)). Capabilities are defined as "a special type of resource, specifically an organizationally embedded nontransferable firm-specific resource, whose purpose is to improve the productivity of the other resources possessed by the firm" (Makadok, 2001, p. 389).

There are some important differences between "assets" and "capabilities." First, capabilities are firm-specific in the sense that "ownership of capabilities cannot be transferred from one organization to another without also transferring ownership of the organization itself" (Makadok, 2001, p. 388), while this does not happen with the assets. Second, and more importantly, capabilities serve primarily to enhance the productivity of assets (Makadok, 2001, p. 389). Subsequently, a narrower definition of resources has been proposed and widely adopted, which differentiates them from capabilities (Grant, 1991): resources are stocks of available production factors that are owned or controlled by the firm, while capabilities, in contrast, refer to a firm's capacity to deploy resources using organizational processes in order to perform important firm tasks. In this study, we adopt this latter discrimination between and definition of resources and capabilities, as it is much more widely used today than the former (see Gruber et al., 2010; Kim et al., 2015; and also for ICT in particular see Ravichandran & Lertwongsatien, 2005; Gu & Jung, 2013; Felipe et al., 2016).

Summarizing, the central idea of the resource-based view is that organizational differences in resources, as well as in capabilities for deploying and exploiting them, explain performance variation of firms (Barney, 1991; Grant, 1991; Makadok, 2001). Consequently, we expect that the profile of a firm's resources and capabilities would be reflected in its investment behavior during an economic crisis. In particular, high levels of these resources and capabilities are expected to enable the firm to manage effectively the crisis, take the appropriate adaptation actions, and reduce its negative consequences (such as sales revenue decrease), thus reducing the need for decrease in investments, including those in ICT. Therefore, some specific resources and capabilities would be possible stabilizing factors of investment expenditures in general, also ICT investment expenditures, during an economic crisis.

In economic literature, human capital, organizational capital, and knowledge capital are considered, besides the standard inputs labor and physical capital, as the most important components of firm resources according to the "new firm model" (Milgrom and Roberts, 1995; Lindbeck & Snower, 2000; Bresnahan et al., 2002; Black & Lynch, 2002; see Arvanitis, 2005 for an overview of this literature). We expect that these three resources will be highly important for handling effectively the crisis and reducing its negative consequences, and therefore the need for investment reduction. In particular, economic crises give rise to big (and usually difficult to predict) changes in firms' external environment. So, firms have to acquire and analyze extensive relevant information and knowledge about these changes from their external environment, and then design and implement appropriate actions for addressing them. These require extensive information and knowledge exchange as well as co-operation among all functional units (marketing, sales, production, procurement, finance, etc.).

High-quality human resources and use of "organic" nonhierarchical forms of organization (such as teamwork, job rotation, and decentralization of decision-making) constitute an important "organizational capital," which will enable the firm to perform better this extensive external information and knowledge acquisition and analysis, and based on them cope better with the crisis, reducing the needs for decrease of all kinds of investment. In particular, teamwork facilitates and enhances crisis-relevant information/knowledge exchange among employees from different functional units, as well as coordination and co-operation among these units, for taking specific actions in order to cope with the crisis. Also, the decentralization of decision-making improves the effectiveness of the extensive information and knowledge processing required for handling the crisis, by transferring part of it from the overloaded top management (especially during economic crisis periods) to the middle and lower management levels. Additionally, human capital and these new nonhierarchical forms of organization enable the identification of valuable new opportunities of ICT use and corresponding ICT investments, which can offer significant business benefits (e.g., significant efficiency improvements) and generate high levels of

business value, which are useful for coping with the difficult crisis conditions. Previous management research has revealed that "organic" structural designs of firms, which are less formal and hierarchical, and include more teamwork, decentralization, and job rotation, are more appropriate and efficient for coping with and surviving in unstable changing environments (Acemoglu et al., 2007; Donaldson, 2001), thus enhancing a firm's organizational agility (defined as the ability to sense changes in the external environment and to respond rapidly, efficiently and effectively to them; see, e.g., Sherehiy et al., 2007).

Finally, R&D increases knowledge capital and enables the firm to make appropriate innovations in its products and services (e.g., develop some simpler and less expensive versions of them), and also in its processes (e.g., for reducing their costs), in order to cope better with the crisis, thus reducing the needs for a decrease of ICT investment expenditures. Based on the above discussion we formulate the following hypothesis:

Hypothesis 3: Overall firm's resource endowment (human capital, organizational capital concerning "organic" nonhierarchical forms of organization, and knowledge capital) help to stabilize ICT investment in a crisis; thus, we expect that these three resources correlate jointly negatively with crisis-induced reduction of ICT-related investment.

The next two research hypotheses 4 and 5 focus on firm's ICT-related resources and capabilities, respectively, and concern their effects on the crisis-induced reduction of ICT-related investment. More specifically, given the high importance of ICT for firms' operations and performance, there has been special interest of IS researchers and practitioners in ICT-related resources and capabilities (Ashrafi & Mueller, 2015; Chae et al., 2018; Chen et al., 2014; Gu & Jung, 2013; Loukis et al., 2021; Lu & Ramamurthy, 2011; Ravichandran & Lertwongsatien, 2005). This research has revealed that firms acquire various types of ICT-related resources, such as ICT infrastructures and ICT personnel, in order to exploit the big potential of ICT. Furthermore, it has identified five main ICT-related capabilities of high importance for firms: the capabilities for ICT usage strategic planning (especially in connection with overall firm strategic plans), for creating ICT-related internal relations (between the ICT unit and the business units) as well as ICT-related external relationships (with firm's ICT vendors), for IS development and for IS operations.

In particular, with respect to ICT-related resources, a good *ICT infrastructure* can provide extensive data that can support and improve the quality of the critical decisions that have to be made during crisis periods, as it enables and supports: i) understanding in depth the specific changes caused by the crisis in a firm's external environment and the consequences of the crisis for the specific firm (e.g., through collection, storage, and processing of sales data by product service, region, etc.); ii) sharing of information and knowledge concerning the crisis consequences for the firm among its employees of different functions; iii) making the appropriate adaptations of production, shipping, storage, and procurement to the decreasing demand for firm's products/services due to the crisis; iv) designing and implementing appropriate actions for managing the crisis (e.g., development and production planning of new products, and/or modifications of the existing ones as well as new production and management processes and/or modifications of existing ones). Previous IS research has revealed that ICT infrastructures can be quite useful for making innovations in products and services as well as internal processes and supply chains (Kuk & Janssen, 2013), and in general enhance firm's organizational agility (Goodhue et al., 2009; Lu & Ramamurthy, 2011), which are necessary and highly important during crisis periods.

The above analysis is expected to hold not only for the "classical" internal on-premises ICT infrastructures, but also for external ICT infrastructures used by the firm through *Cloud Computing* services, which enable the rapid and low-cost access to a wide variety of infrastructure, platform, and software resources, increasing firm's performance, innovation, and organizational agility (Loukis et al., 2019; Luo et al., 2018; Marston et al., 2011; Müller et al., 2015).

Furthermore, *ICT-related human resources (ICT personnel)* are expected to contribute significantly to the more efficient and effective exploitation, adaptation, and enrichment of a firm's ICT infrastructure, and in this way to contribute to conducting effectively the above-mentioned tasks i) to iv), resulting in a better handling of the crisis. Furthermore, ICT personnel can contribute to the identification of highly valuable opportunities of ICT use for coping with the crisis, and the design and implementation of the corresponding ICT investments. Previous ICT research has concluded that a firm's ICT personnel are highly important for the improvement of firm's organizational agility (Bi et al., 2014; Fink et al., 2007), as well as innovation capacity (Arvanitis, Loukis, Diamantopoulou, & Zahir Irani, 2013).

Therefore, we expect that having a good ICT infrastructure, also using external ICT resources through Cloud Computing services, and at the same time employing specialized ICT personnel, will allow the firm to cope better with the crisis, reducing the needs for decrease of ICT investment. Based on the above discussion, we formulate the following hypothesis:

Hypothesis 4: ICT-related resource endowment (ICT infrastructure, ICT personnel, Cloud Computing) help to stabilize ICT investment in a crisis; thus, we expect that these three resources correlate jointly negatively with crisis-induced reduction of ICT-related investment.

Furthermore, we expect that firm's *ICT-related capabilities*, as they concern the optimization of ICT resources mobilization and deployment (Ashrafi & Mueller, 2015; Chae et al., 2018; Lu & Ramamurthy, 2011), will enable the firm to exploit better and more effectively the potential of ICT during the crisis for coping with it, and in this way they will contribute to a weakening of the negative impact of crisis on the firm, and therefore on its ICT investment. Previous IS research has shown that ICT-related capabilities can enhance firm's organizational agility (Chen et al., 2014; Felipe et al., 2016; Lu & Ramamurthy, 2011), which is highly important during economic crisis periods.

We focus in this study on four out of the above-mentioned five main ICT-related capabilities identified in previous relevant research literature, for which we expect – for the reasons mentioned below – to affect ICT investment behavior in the crisis: these are the capabilities for ICT usage strategic planning in connection with overall firm strategic plans (also referred to as "ICT strategic alignment" (Wu et al., 2015)), ICT internal relations (between the ICT unit and the business units), ICT external relationships (with firm's ICT vendors), and IS development. For the fifth ICT-related capability, the one for IS operations, we do not expect it to have a considerable impact on ICT investment behavior in the crisis.

In particular, the ICT strategic planning/alignment capability will enable the firm to have a more strategic approach to ICT use for coping with the crisis, oriented toward and focused on supporting as well as enhancing and enriching firm's overall strategy for dealing with the crisis. Previous IS research has concluded that ICT strategic alignment has a positive impact on organizational agility (Tallon & Pinsonneault, 2011), which is highly important during economic crisis periods. The capability for ICT internal relations can further serve to a better co-operation and knowledge exchange between the ICT unit and the business units for optimal exploitation of firm's ICT infrastructure for making the required adaptations to the crisis, and for coping with the crisis in general, and also for collaboratively identifying highly valuable opportunities of ICT use for coping with the crisis, and then for the design and implementation of the corresponding ICT investments. Also, the capability for ICT external relations will result in a better co-operation and knowledge exchange with firm's ICT vendors, which will enable a better exploitation of the existing ICT infrastructure for coping with the crisis and making the required adaptations, and also identifying valuable opportunities for investing in the extension and upgrade of this ICT infrastructure/.

Furthermore, we analyze the IS development capability into three components: a) capability to develop new applications, b) capability to implement modifications of existing applications, and c) capability to implement interconnections/integrations of existing applications. We expect that these three IS development-related capabilities will be highly important in order to provide the required ICT support (new applications as well as modifications and interconnections/integrations of existing ones) for addressing the new needs (e.g., for new or modified processes, products, and services) that the crisis has generated.

Thus, the existence of the above ICT-related capabilities would enable the firm to react more effectively to the crisis and reduce its negative consequences, and therefore the need for ICT investment decrease due to the crisis. Furthermore, we expect that they will also improve firm's ability to identify better and more strategic opportunities of ICT investment, to implement them, and finally to use and exploit them better. Based on the above discussion, we formulate the following hypothesis:

Hypothesis 5: ICT-related capabilities help to stabilize ICT investment in a crisis; thus, we expect that these capabilities correlate jointly negatively crisis-induced reduction of ICT-related investment.

Sectoral environment factors

With respect to the external sectoral environment, we expect that the competition conditions at firm's product market will affect its ICT investment behavior. In economic theory and empirics, the relationship between investment and competition is not monotonous (see, e.g., Schmutzler, 2013 for investment in general and

P. Aghion et al., 2005 arguing for a reverse U-shaped relationship between market structure as measure of competition and R&D investment) and depends heavily on firms' ability to finance investment. Firms with intensive competition in polypolistic markets (i.e. markets with many competitors, which we assume to be mostly the case in this paper) are likely to have in general, even in economically "good" times, difficulties to finance investment, as their price-cost margins are expected to be low. As a consequence, in "bad" business times (i.e. in periods of economic crisis) they are expected to tend to reduce investment, i.e., to show pro-cyclical behavior. Thus, the relationship between ICT investment and competition pressure is expected to be negative during a crisis, if a firm reacts pro-cyclical to crisis, which is mostly the case (Archibugi et al., 2013b; Arvanitis & Woerter, 2014 for investment in innovation). Therefore, for the assumed pro-cyclical behavior, we expect that increased (price and non-price) competition pressure would increase crisis vulnerability with respect to ICT investment.

Further, high obsolescence rate of products/services and/or their technologies enhances technological competition pressure, so we expect that it will increase crisis vulnerability with respect to ICT investment expenditures, given that firms behave pro-cyclically (see above), which is mostly the case. The idea is that a high obsolescence rate makes it more difficult for most firms to cope with the crisis, because the financial restrictions (low cash flow, low prices) that exist during the crisis do not allow to invest as much and as quickly as necessary in order to survive at the market (Vives, 2008; Woerter et al., 2010), reducing the availability of financial resources for ICT investment. Based on the above discussion, we stated the following hypothesis:

Hypothesis 6: Competition conditions (including intensity of price competition and non-price competition as well as degree of obsolescence of products/technologies) correlate jointly positively with crisis-induced reduction of ICT-related investment.

Data

Sampling

We collected the data for this study through a survey that has been conducted specifically for this study. The firm sample on which the survey is based was constructed as follows: The "universe" of Greek firms as conceived in this study is given by the original sample of the well-known large Greek business information and services firm ICAP (see https://www.icapcrif.com for more information) of 6429 firms (see column 1 in Table A1 for the composition by industry of the original sample), which is the only source for firm data in Greece that is publicly available (as data collected by government agencies are not publicly available); this sample of Greek firms is regarded as highly reliable and is used for many important surveys. The available information in the ICAP sample refers mainly to firm size (number of employees) and industry affiliation (while all the other information used in our study has been collectd through our own survey). An intermediate (more manageable) sample was constructed with the same composition by industry and size as the original sample, but reduced to about 50% of the total number of firms; the firms for each industry sub-sample were chosen randomly out of the original sample (Table A1, column 2). A questionnaire (the questions it included are described in section 4) was sent to the 3308 firms of the intermediate sample and we received 363 valid (response rate 11%). Table A2 in the appendix shows the composition of the respondent firms' sample we used in our study by industry and firm class size.[3]

It should be mentioned that already the original sample is not representative of the composition of Greek firms by industry. In the Greek economy, there are thousands of small and very small firms in trade, especially in retail trade, in tourism, especially in catering, and also in construction. The ICAP sample is not representative of this composition and focuses on the most technologically developed part of the Greek economy: on manufacturing (30.7% of the firms of the original sample) and also on modern service industries (such as computer services, business services, and transport/communication; 21.5% of the service firms of the original sample), though it includes a high percentage of trade and tourism firms (78.5% of the service firms of the original sample). The intermediate sample has a similar composition with respect to industry. The sample of the respondent firms is even more focused on manufacturing (40.2% of the firms) and on modern services (27.4%). Therefore, this structure of the respondent firms' sample corresponds to the technologically most developed part of the Greek economy, on which we focus in this study.[4] It is particularly interesting to investigate the ICT-related crisis resilience and the factors affecting it for this technologically developed part of the Greek economy, which is more likely to recover from the crisis.

ICT-related crisis vulnerability

In Table 1 we can see the relative frequencies among the firms of our sample of the six possible values of our

Table 1. Impact of crisis 2009–2014 on ICT investment expenditures (relative frequencies (in %)) of all values of the dependent variable ICT_INVEX (impact of crisis 2009–2014 on overall ICT investment expenditures).

Impact	Relative frequency (%)
Increase	11.6
No impact	30.0
Small decrease	15.5
Medium decrease	20.7
Large decrease	15.5
Very large decrease	6.7

dependent variable, which is the crisis-induced change of ICT investment expenditures (increase, no impact, small decrease, medium decrease, large decrease, very large decrease – see section 4 for more details). We can see that 58.4% of them reported decrease ("small decrease" up to "very large decrease") of ICT investment, with more than one-fifth of them reporting "large decrease" or "very large decrease." These results indicate the negative impact of the crisis on firms' ICT investment, as they seem to exhibit mainly pro-cyclical behavior with respect to ICT investment. However, we can see that the remaining 41.6% of the sample firms reported "no impact" or even "increase" of ICT investment. This indicates that a considerable share of firms has exhibited a significant resilience with respect to their ICT-related behavior and has refrained from reducing their ICT investment. Finally, we can see that only 11.6% of the firms have reported an increase in their ICT investment, which indicates that only a small minority of firms could afford anti-cyclical behavior with respect to ICT investment during the crisis.

Model specification

Research model

As main dependent variable, we have used a six-level ordinal variable that measures the extent of reduction of firm's ICT investment expenditures during the long Greek crisis period 2009–2014 (ICT_INVEX; see Table A3 in the appendix for the definition of all variables). This variable is considered as a measure of firm's ICT-related crisis vulnerability, as larger reduction of ICT investment expenditures during crisis indicates higher firm's ICT-related vulnerability to the crisis.

We distinguish six groups of factors that might have affected ICT investment behavior during the crisis period 2009–2014, which refer directly to our six research hypotheses (see Figure 1). First, we consider three groups of internal factors, one that refers to overall resource endowment (measured jointly by three single variables: R&D, HQUAL, ORG), a second one referring to ICT-related resource endowment (measured jointly by three single variables: ICT_PERS, ICT_INFRA, CLOUD), and a third one referring to ICT-related capabilities (measured jointly by six single variables: ICT_CAP1 to ICT_CAP6), respectively. Further, we examine three groups of external factors: one referring to the competition conditions in firm's product market (measured jointly by three variables: P_COMPET, NP_COMPET, OBSOL), a second one covering liquidity conditions with respect to transaction partners (banks, customers, and providers) measured by the composite variable LIQUIDITY, and a third one related to macroeconomic conditions (overall development of domestic private and public sector demand and prices) measured by the composite variable MACRO. The exact specifications/definitions of the above variables are described in the following section and in Table A3 in the appendix.

Specification of the variables

Resource endowment

Overall resource endowment (see hypothesis 3) is proxied by one variable for knowledge capital (R&D; the existence of R&D activities), one for human capital (HQUAL; share of employees with tertiary-level education), and one for organizational capital (ORG; use of organic non-hierarchical forms of organization, such as teams, job rotation, decentralization of decision-making, etc.). Internal ICT-related resources (see hypothesis 4) are measured through three variables concerning average intensity of use of the main ICT enterprise applications (ERP, CRM, SCM, Business Intelligence/Business Analytics Systems, and Collaboration Support Systems (ICT_INFRA), the employment of ICT personnel (ICT_PERS; share of ICT-specialized personnel), and the use of external ICT resources of Cloud Computing providers (CLOUD), respectively).

ICT-related capabilities

We also examine the effects of six important ICT-related capabilities on firms' crisis vulnerability with respect to ICT investment expenditures (ICT_CAP1 to ICT_CAP6; see research hypothesis 5). These ICT-capabilities refer to IS development (discriminating between capabilities for rapid implementation of changes in existing applications or IS to cover specific firm needs, rapid development of new ICT applications to cover specific firm needs, and rapid realization of interconnection and integration of existing ICT applications). Further, they include capabilities for ICT internal and external relations (capabilities for good cooperation and information exchange between ICT personnel and

ICT users inside the firm, and for good cooperation and information exchange with a firm's ICT suppliers of hardware, software, and networks). Finally, they also include the capability for ICT strategic planning-alignment (capability for developing ICT plans that are connected with overall firm strategy).

Competition conditions

Competition conditions at the product market are measured through three variables (see hypothesis 6): one variable for the intensity of price competition (P_COMPET), a second one for the intensity of non-price competition (competition with respect to quality, technology, etc.; NP_COMPET), and a third one for the rate of obsolescence of a firm's products and services (OBSOL).

Liquidity conditions

For measuring possible crisis-induced liquidity constraints (see hypothesis 2) we use a composite variable (LIQUIDITY) calculated as the average of three variables measuring the extent of decrease of credit limits of providers and banks, as well as the decrease of the paying willingness of customers.

Macroeconomic conditions

For measuring macroeconomic conditions (see hypothesis 1) we use a composite variable (MACRO) calculated as the average of four variables measuring the extent of crisis-induced decrease of private domestic and foreign demand as well as of demand of the public sector, and also a measure of the extent of decrease of product and service prices during the crisis.

Other (control) variables

We control for possible internal problems before the crisis (insufficient control of costs, over-investment in equipment, buildings, and/or storage capacity as well as over-expansion due to takeovers and mergers; these individual variables are used to construct the composite variable INTER_PRO), which might increase a firm's overall crisis vulnerability, and consequently also its vulnerability as to ICT investment expenditures. Further, we control for firm age, firm size, and industry affiliation.

So, based on the above variables we estimated a regression model for ICT investment expenditures reduction, which is formally expressed as follows (see Table A3 in the appendix for the definition of all variables; Table A4 of the appendix shows descriptive statistics of the variables of the model):

$$\begin{aligned} ICT\_INVEX_i &= \alpha_0 + \alpha_1 R\&D_i + \alpha_2\, HQUAL_i \\ &+\alpha_3\, ICT\_PERS_i + \alpha_4\, ICT\_INFRA_i + \alpha_5\, CLOUD_i \\ &+ \alpha_6\, ORG_i + \alpha_7\, ICT\_CAP\_1_i + .. \\ &+ \alpha_{12}\, ICT\_CAP\_6_i + \alpha_{13}\, INTER\_PRO_i \\ &+ \alpha_{14}\, P\_COMPET_i + \alpha_{15}\, NP\_COMPET_i \\ &+ \alpha_{16}\, OBSOL_i + \alpha_{17}\, LIQUIDITY_i \\ &+ \alpha_{18}\, MACRO_i + \alpha_{19}\, LAGE_i + \alpha_{20}\, Medium \\ &- sized_i + \alpha_{21}\, Large_i + industrycontrols + e_i \end{aligned} \tag{1}$$

(for firm i)

Results

Econometric issues

As mentioned in the previous section, the dependent variable is a six-level ordinal variable, which refers to the extent of reduction of ICT investment during the crisis period 2009–2014. Given the nature of the dependent variable, the appropriate estimation method is ordered probit regression ("oprobit" procedure of STATA).

The independent variables that refer to firm internal factors are measured either for 2014 (metric variables) or for the period 2012–2014 (ordinal variables), with the exception of the variable for overall internal problems, which explicitly refers to the time before 2009 (see Table A3 in the appendix). Thus, some of the independent variables reflect a firm's condition at the end and not at the beginning of the observed crisis period. As a consequence, they could have been affected by the crisis and could reflect a firm's adaptation to the crisis. In this sense, they are endogenous. Logically, there exist the following three possibilities. First, these factors have changed so that they could have influenced positively crisis vulnerability or, vice versa, crisis vulnerability could have affected these factors positively. Second, these factors have changed so that they could have influenced negatively crisis vulnerability or, the other way around, crisis vulnerability could have affected these factors negatively. Third, they have remained as structural factors more or less unchanged during the crisis period contributing to either increase or decrease of crisis vulnerability. We cannot identify which effect of such possible interactions between dependent and independent variables (reverse causality) is dominant, but we get in the estimates the net effect for each of these factors independent of which kind of effects has been at work. Thus, we get knowledge of what has happened at the end of the process, i.e. which factors correlate positively or negatively with crisis vulnerability at the

end of the day, under the assumption that only the magnitude but not the sign of possible effects could have changed during the observed crisis period. This would (still) be an important insight.

For some factors, we have good reasons to consider them as structural factors that would not have changed considerably during the crisis, just because they are factors that could be expected to reduce crisis vulnerability, thus to act anti-cyclically (e.g., ICT capabilities, ICT and human capital endowment, existence of R&D activities). We also have good reasons to assume that competition conditions at the product market are also of structural nature. We cannot exclude that the overall competition pressure became stronger during the crisis period, but with only small shifts as to the relative strength of competition pressure at different markets.

The endogeneity issue is less a problem in the case of the external factors such as decrease in overall and crisis-induced liquidity constraints, which are explicitly reported in the survey as factors that could have affected a firm's economic activities before or during the observed crisis period (see Table A3 in the appendix), thus reflecting factors that could have directly affected crisis vulnerability with respect to ICT investment expenditures.

The problem of possible unobserved, particularly time-variant, heterogeneity still remains, even though we control extensively for many possible explaining factors as well as for 9 industries and 3 firm size classes, thus reducing to some extent the possibility of time-invariant heterogeneity. For these reasons, no claims are made for causality effects but only for conditional correlation effects that might yield useful insights for possible causality effects in accordance to our research hypotheses.

Marginal effects were not estimated because most of the 21 right-hand variables in equation (1) are 5-level ordinal variables or binary variables; only 3 of them are metric variables.

Estimates for overall ICT investment expenditure

The estimated models of the crisis-induced reduction of ICT investment expenditure (ICT_INVEX) are shown in Table 2. In order to avoid multi-collinearity problems due to the high correlation among the six individual ICT-related capabilities, we estimated six models, with each of them containing one of these variables as independent variable (columns 1 to 6 in Table 2) and another model including their average as independent variable (column 8 in Table 2). Finally, column 7 shows the estimates with all capability variables in the same model. The estimated models have values of Pseudo R^2 between 0.119 and 0.131 that are rather low, but still satisfactory for cross-section micro data analysis. The high significance of the Wald chi2 statistics of all models demonstrates their overall statistical validity.

Resource endowment

The separate joint tests for the examined groups of overall resources and ICT-related resources are not statistically significant (Table A4 in the appendix). Also, the joint effect for the components of both groups of resource endowment is statistically insignificant (Table A4 in the appendix). Nevertheless, we find statistically significant negative effects for two important single resource factors, namely the use of new forms of organic nonhierarchical workplace organization (such as teamwork, job rotation, and decentralization) and the use of Cloud Computing. These two resources increase a firm's capacity to flexibly react to the crisis; thus, its capacity to reduce the negative impact of the crisis on its activities, and therefore the need to reduce ICT investment.

These results indicate that the use of new forms of organic workplace organization enables a more extensive and efficient exchange of information and knowledge among employees from different functions, and also a better co-operation and co-ordination among them for taking effective response actions in order to cope with the crisis. This finding is in accordance to previous research, which concludes that the organic nonhierarchical organizational designs are highly important for coping with and surviving in unstable and changing external environments (Acemoglu et al., 2007; Donaldson, 2001), and enhance a firm's organizational agility (Sherehiy et al., 2007).

Also, our results indicate that the use of Cloud Computing enables the rapid and low-cost access to a wide variety standardized and commoditized ICT resources (infrastructure, platform, and software ones), which are required for the support of crisis response actions; this enables a better re-action to the crisis, reducing its negative impact on the firm, and therefore reducing the need for decreasing ICT investment. Our result is also in accordance with previous research concluding that the use of Cloud Computing can increase firm's organizational agility (Loukis et al., 2019; Marston et al., 2011; Müller et al., 2015). Furthermore, the use of standardized and commoditized ICT resources through Cloud Computing services allows a firm's ICT investment to focus on some highly valuable firm-specific as well as operation-critical components. This decreases a firm's propensity to reduce ICT investment as a response to the crisis.

Table 2. Dependent variable: ICT_INVEX; factors explaining crisis behavior with respect to ICT investment expenditures.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
R&D	0.018	0.018	0.029	0.050	0.018	0.026	0.065	0.018
	(0.139)	(0.139)	(0.138)	(0.137)	(0.140)	(0.141)	(0.140)	(0.138)
HQUAL	0.309	0.302	0.308	0.348	0.306	0.355	0.422	0.338
	(0.282)	(0.284)	(0.280)	(0.275)	(0.282)	(0.282)	(0.277)	(0.278)
ICT_PERS	−0.180	−0.207	−0.133	−0.105	−0.232	−0.163	−0.165	−0.120
	(0.346)	(0.354)	(0.345)	(0.344)	(0.343)	(0.344)	(0.353)	(0.350)
ORG	−0.295**	−0.298**	−0.302**	−0.308**	−0.306**	−0.273**	−0.308**	−0.282**
	(0.134)	(0.135)	(0.132)	(0.132)	(0.132)	(0.133)	(0.136)	(0.133)
ICT_INFRA	−0.042	−0.053	−0.031	−0.019	−0.053	−0.006	−0.013	−0.025
	(0.065)	(0.065)	(0.065)	(0.066)	(0.067)	(0.071)	(0.070)	(0.068)
CLOUD	−0.355**	−0.359**	−0.343**	−0.317**	−0.357**	−0.355**	−0.354**	−0.329**
	(0.153)	(0.154)	(0.153)	(0.153)	(0.154)	(0.152)	(0.157)	(0.153)
ICT_CAP_1	−0.056						0.053	
	(0.060)						(0.099)	
ICT_CAP_2		−0.029					0.086	
		(0.059)					(0.083)	
ICT_CAP_3			−0.090*				−0.093	
			(0.054)				(0.095)	
ICT_CAP_4				−0.156**			−0.234**	
				(0.063)			(0.111)	
ICT_CAP_5					−0.020		0.146	
					(0.061)		(0.097)	
ICT_CAP_6						−0.117**	−0.081	
						(0.060)	(0.083)	
ICT_CAP_AV								−0.120*
								(0.072)
INTER_PRO	0.058	0.058	0.065	0.055	0.052	0.048	0.063	0.042
	(0.078)	(0.078)	(0.079)	(0.079)	(0.078)	(0.079)	(0.079)	(0.079)
P_COMPET	−0.027	−0.029	−0.026	−0.033	−0.030	−0.048	−0.042	−0.025
	(0.069)	(0.069)	(0.069)	(0.069)	(0.068)	(0.067)	(0.068)	(0.068)
NP_COMPET	0.048	0.052	0.045	0.038	0.053	0.059	0.040	0.045
	(0.073)	(0.073)	(0.073)	(0.074)	(0.073)	(0.073)	(0.074)	(0.073)
OBSOL	0.173***	0.176***	0.178***	0.162***	0.173***	0.164***	0.160**	0.159**
	(0.064)	(0.064)	(0.065)	(0.065)	(0.065)	(0.065)	(0.068)	(0.065)
LIQUIDITY	0.208***	0.208***	0.209***	0.217***	0.210***	0.203***	0.229***	0.275***
	(0.067)	(0.067)	(0.066)	(0.066)	(0.067)	(0.067)	(0.068)	(0.075)
MACRO	0.542***	0.542***	0.534***	0.525***	0.542***	0.549***	0.515***	0.507***
	(0.088)	(0.087)	(0.087)	(0.087)	(0.087)	(0.088)	(0.089)	(0.090)
AGE	0.000	0.000	0.000	0.0000	0.000	0.000	−0.000	0.001
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.000)	(0.003)	(0.003)
Medium-sized	0.121	0.100	0.137	0.182	0.093	0.153	0.179	0.151
	(0.142)	(0.142)	(0.145)	(0.146)	(0.144)	(0.142)	(0.146)	(0.146)
Large	0.460*	0.426*	0.468*	0.561**	0.423	0.525**	0.553**	0.524**
	(0.259)	(0.257)	(0.257)	(0.264)	(0.263)	(0.256)	(0.258)	(0.263)
Industry dummies (9)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Thresholds (5)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	306	306	306	306	306	306	306	306
Pseudo R^2	0.120	0.119	0.121	0.125	0.119	0.122	0.131	0.126
Wald Chi2	161.0	162.6	161.8	167.2	161.7	158.9	173.4	172.1
Prob > chi2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Log pseudolikelihood	−456.1	−456.4	−455.2	−453.2	−456.5	−454.8	−450.2	−452.6

Ordered Probit estimates; five thresholds are not shown; heteroscedasticity-robust standard errors in brackets; *, **, and *** denote statistical significance at the 10%-, 5%, and 1%-test level, respectively.

Thus, the introduction of new forms of organic non-hierarchical workplace organization and the use of Cloud Computing contribute to a weaker ICT-related impact of crisis, i.e. to a reduction of ICT-related crisis vulnerability. However, the existence of R&D activities, the (overall or ICT specific) personnel, and the ICT infrastructure (intensity of use of standard ICT enterprise applications such as ERP, SCM, CRM, Business Analytics, and Collaboration Support Systems) do not seem to be significantly correlated with ICT investment crisis vulnerability. Therefore, *hypothesis 3* and *hypothesis 4* are partly confirmed only for the above two important factors.

ICT-related capabilities

The joint effect of all ICT-related capabilities is negative and statistically significant (Table A4 in the appendix). Because of rather high multicollinearity among the ICT capability variables, as mentioned in section 4, we also present in Table 2 estimates of equation (1) separately for each ICT capability variable and also for the average of the six ICT capability variables. The negative and statistically significant values of the joint effect of the ICT-related capabilities (and also of the effect of the average of the six examined ICT-related capabilities; ICT_CAP_AV, see last column of Table 2) indicate

that high levels of ICT-related capabilities weaken the negative impact of the crisis on ICT investment, being more important from this perspective than ICT resources. We can see from Table 2 that weakening of the crisis effect on ICT investment is achieved mainly through the development of capabilities for interconnection/integration of the existing ICT applications, intensive co-operation and information exchange between ICT personnel and ICT users, and ICT strategic planning/alignment. The ICT strategic planning/alignment capability enables the firm to have a more strategic approach to ICT use for coping with the crisis, oriented toward and focused on supporting as well as enhancing a firm's overall strategy for dealing with the crisis, reducing its negative impact on the firm in general and on ICT investment in particular. This result is also in accordance to previous IS research that has revealed that ICT strategic alignment has a positive impact on organizational agility (Tallon & Pinsonneault, 2011), which is highly important in economic crisis periods. The capability to develop intensive co-operation and information exchange between ICT personnel and ICT users enables a better and more effective exploitation of the existing ICT infrastructure for handling the economic crisis, based on the combination of the perspectives and the knowledge of these two groups; furthermore, it enables a close collaboration between them for identifying highly valuable opportunities of ICT use for coping with the crisis, and then for the design and implementation of the corresponding ICT investments. Finally, the capability for rapid interconnection and integration of existing ICT applications of the firm allows the combination and better exploitation of their data and functionalities in order to address the new needs that the crisis generates. On the whole, *hypothesis 5* receives significant empirical support.

Competition conditions

The joint effect of the variables for the competition conditions is not statistically significant (Table A4 in the appendix). We find no statistically significant effect of price or non-price pressure. This happen probably because competition pressure is in general low in most sectors of the Greek economy (see, e.g., Arvanitis, Loukis, & Diamantopoulou, 2013). However, we find a statistically significant positive effect of the obsolescence rate of firm's products/services and/or their technologies. This indicates that if a firm's products, services, and/or their technologies become quickly obsolete, this firm would tend to avoid in crisis periods some of the ICT investment required for supporting them. Possible reasons for this might be: a) this high obsolescence rate necessitates high levels of investments in order to survive, which is quite problematic during crisis periods due to the existing financial constraints, which reduces the availability of financial resources for ICT investments; b) some of the ICT investment might lead to IS that cannot be utilized for long time during the crisis, because they would have to be soon replaced or significantly modified in order to keep up with the pace of change of products and services. So, *hypothesis 6* is only partly confirmed for the obsolescence variable.

Macroeconomic conditions

As expected, macroeconomic effects (referring to the decrease in demand for a firm's products and services as well as of their prices, and also liquidity problems due to decrease of credit limits by banks and suppliers or decrease of the paying willingness of customers) enhance ICT-related crisis vulnerability. Overall unfavorable economic conditions and unfavorable behavior of important transaction partners affect negatively investment behavior of firms in general, even if not all firms to the same extent. Thus, *hypothesis 1* and *hypothesis 2* are confirmed.

Overall internal problems

Pre-existing problems concerning insufficient cost controls, over-investment in equipment, buildings or storage capacity or over-expansion by takeovers or mergers are not significantly correlated with ICT-related crisis vulnerability.

Finally, large firms seem to be more ICT crisis-vulnerable than medium-sized and small firms, presumably due to lower flexibility to react to the crisis compared with smaller firms.

Estimates for categories of ICT investment expenditures

In a further step, we used the same specification as in Table 2 to estimate models for the crisis-induced change of the four main categories of ICT-related investment, namely investment in ICT hardware (ICT_INVEX1), ICT software (ICT_INVEX2), ICT training (ICT_INVEX3), and ICT consulting (ICT_INVEX4). The estimates for these four 6-level ordinal dependent variables are presented in Table 3 (columns 1 to 4). Also, for these estimates, we yield satisfactory values of Pseudo R^2 and high significance of the respective Wald chi2 statistics.

The results in Table 3 yield some interesting additional insights. Primarily, they allow us to recognize to which specific ICT investment category the overall effects in Table 2 can be traced back. We find for all four investment categories statistically significant negative correlations for the organizational variable (ORG)

Table 3. Dependent variables: ICT_INVEX1 to ICT_INVEX4; factors explaining crisis behavior with respect to four main categories of ICT investment expenditures.

	(1)	(2)	(3)	(4)
	ICT_INVEX1	ICT_INVEX2	ICT_INVEX3	ICT_INVEX4
R&D	−0.003	0.080	0.036	0.026
	(0.138)	(0.139)	(0.137)	(0.140)
HQUAL	0.388	−0.047	0.049	0.252
	(0.264)	(0.258)	(0.273)	(0.253)
ICT_PERS	0.155	0.097	−0.257	−0.305
	(0.333)	(0.360)	(0.348)	(0.290)
ORG	−0.281**	−0.257*	−0.371***	−0.342***
	(0.135)	(0.134)	(0.132)	(0.129)
ICT_INFRA	−0.014	−0.048	−0.018	0.016
	(0.066)	(0.062)	(0.066)	(0.066)
CLOUD	−0.291**	−0.223	−0.133	−0.117
	(0.141)	(0.149)	(0.152)	(0.157)
ICT_CAP_AV	−0.074	−0.059	−0.168***	−0.159**
	(0.069)	(0.073)	(0.067)	(0.070)
INTER_PRO	0.033	0.101	0.152*	0.165**
	(0.081)	(0.077)	(0.080)	(0.080)
P_COMPET	−0.026	−0.018	0.024	−0.006
	(0.066)	(0.074)	(0.072)	(0.065)
NP_COMPET	0.000	−0.020	0.014	−0.020
	(0.071)	(0.071)	(0.071)	(0.066)
OBSOL	0.130*	0.086	0.126*	0.072
	(0.067)	(0.067)	(0.076)	(0.073)
LIQUIDITY	0.239***	0.248***	0.206***	0.163**
	(0.073)	(0.073)	(0.068)	(0.068)
MACRO	0.527***	0.427***	0.457***	0.481***
	(0.095)	(0.092)	(0.083)	(0.089)
AGE	0.000	0.000	0.004	0.004
	(0.003)	(0.003)	(0.003)	(0.003)
Medium-sized	0.076	0.102	−0.113	−0.110
	(0.140)	(0.150)	(0.152)	(0.142)
Large	0.581**	0.522**	0.061	0.020
	(0.256)	(0.258)	(0.218)	(0.228)
Industry dummies (9)	Yes	Yes	Yes	Yes
Thresholds (5)	Yes	Yes	Yes	Yes
N	306	306	306	306
Pseudo R^2	0.111	0.097	0.115	0.101
Wald Chi2	137.9	118.5	125.2	118.8
Prob > chi2	0.000	0.000	0.000	0.000
Log pseudolikelihood	−464.4	−462.8	−435.8	−458.0

Ordered Probit estimates; five thresholds are not shown; heteroscedasticity-robust standard errors in brackets; *, **, and *** denote statistical significance at the 10%-, 5%, and 1%-test level, respectively.

and statistically significant positive ones for the liquidity variable (LIQUIDITY) and the variable for overall demand decrease (MACRO). Therefore, the first factor seems to robustly stabilize the crisis-induced reduction of all four investment categories, while on the contrary the other two factors increase it. There is also a weak tendency to a negative correlation of Cloud Computing, but this variable is statistically significant only in the estimates for hardware investment reduction. Further, the combined effect of six important ICT-related capabilities (ICT_CAP_AV) is significantly negative only for investment in ICT training and consulting, but not for investment in hardware and software. This indicates that firms disposing of high levels of ICT-related capabilities show a lower tendency to reduce investment in "soft" ICT resources (such as training and consulting) than in "hard" ICT resources (such as computers and software). In times of financial constraints, when expansion and renewal of "hard" resources is financially difficult, ICT-related capabilities may enable a firm to better utilize existing ICT infrastructure (hardware and software) and make less investment in infrastructure. This enables using the limited financial resources for avoiding big reductions of investments in "soft" ICT resources, which are related to a firm's specialized human capital (both internal, belonging to the firm, or external, provided by consulting firms), and would lead to loss of know-how that cannot be easily compensated.

Summary and conclusions

Summary

Economic crises are an inevitable trait of market-based economies, appear repeatedly and constitute severe "shocks" in firms' external environment, which have

quite negative impact one hand on the production, employment, and procurement activities of firms, and, on the other hand, on their investments. The reduction of firms' investments during economic crises can result in technological backwardness and obsolescence, and finally impair their future competitiveness and even threaten their survival. However, the extent of these negative impacts differs considerably among firms, so it is quite useful to identify factors that affect their magnitude (increasing or decreasing it) at firm-level, which will enable firms to be better prepared for managing future economic crises, reduce their vulnerability, and increase their resilience to them. In this direction, we have investigated the effects of three groups of internal factors and three groups of external factors on firms' behavior during the 2008 economic crisis with respect to an important type of investment, the ICT investment. The firm-level data used for this study come from Greece, a country that has recently experienced a deep and long economic crisis.

Our study has identified a series of factors that weaken the negative impact of economic crisis on firm's ICT investment. In particular, we found that the use of "organic" nonhierarchical forms of workplace organization as well as the use of Cloud Computing (as ICT-related resource) contribute to a weaker impact of crisis on ICT investment of firms, i.e. to a reduction of their ICT-related crisis vulnerability, making them more resilient to economic crises, by increasing their capacity and flexibility to react to such crises. However, the joint effects of the examined overall and ICT-related resources on ICT investment were found insignificant.

Further, weakening of the crisis negative impact on ICT investment is achieved through a firm's ICT-related capabilities. The joint effect of the examined ICT-related capabilities on ICT investment is significantly negative, which indicates the importance of these capabilities for making the firm more resilient to the crisis, reduce its ICT investment vulnerability. Particularly relevant are the capabilities for interconnection/integration of the existing ICT applications, for the development of intensive cooperation and information exchange between the ICT personnel and the ICT users, and for ICT strategic planning connected with overall firm strategy (ICT business alignment). These capabilities also contribute to a higher flexibility of firm activities, which is particularly relevant in order to be able to react adequately to crisis and reduce the negative impact of it. Furthermore, these ICT-related capabilities enable the generation of more value from firm's ICT investment, so they decrease a firm's propensity to reduce it as a response to the crisis.

Furthermore, our study has identified a series of factors that strengthen the negative impact of the crisis on a firm's ICT investment: macroeconomic conditions of demand decrease, quick obsolescence of a firm's products and services, and unfavorable liquidity conditions (due to decrease of the credit limits by banks and suppliers, and also of the paying willingness of customers). On the contrary, price and non-price competition pressure do not seem to affect ICT-related crisis vulnerability.

Implications for research and practice

Our study has interesting implications for research and practice. From a research perspective, it creates valuable new knowledge on a highly important topic for firms, and for the economy and society in general that had not been previously investigated: the internal and external factors that weaken or strengthen firms' vulnerability to the most severe external environment shock they face, the economic crises that repeatedly appear in market economies, with respect to ICT investment. This constitutes an important contribution of new knowledge to the information systems domain concerning the effects of external environment on the utilization and exploitation of ICT by firms. Also, it constitutes an important contribution to the existing body of knowledge concerning economic crises, which can be quite useful for reducing their negative impact on firms, and for the economy and the society in general. Furthermore, the findings of our study make a contribution to an ongoing highly important theoretical debate concerning the impact of firm's resources and capabilities on different aspects of its performance in various contexts: we have found that ICT capabilities make a much stronger impact than ICT resources on firm's performance concerning ICT investment in an economic crisis context. Our study opens up new directions of research in a wider and minimally explored area: the determinants of the magnitude of the negative impact of economic crises on various aspects of firm's behavior, operation, and performance. The research framework and the research hypotheses we have developed in this study, as well as their theoretical foundations, can be quite useful for future research in this critical area.

From a practitioner perspective, our analysis yields some new practice-relevant knowledge and insights, first, about the firm characteristics, particularly ICT-related characteristics, and, second, about the characteristics of a firm' s economic environment that contribute to a weakening or to an increase in firm's vulnerability to economic crisis regarding ICT investments. These insights give to firms' managers useful directions in order to improve their crisis management with respect

to the ICT, which are highly important technologies for their efficiency, innovation, performance, and competitiveness. In particular, for being more resilient to economic crises firms should have to adopt new "organic" nonhierarchical forms of workplace organization (such as teamwork and decentralization), adopt and exploit Cloud Computing, and also develop a series of ICT-related capabilities. These seem to be factors that allow a firm to adapt its behavior to the unfavorable economic conditions of a crisis, and respond effectively to it, reducing the need to resort to reductions in its ICT investment.

Limitations of the study

There are of course also some limitations in this study, the most important one being that due to lack of annual data, also for years before the start of the crisis, a comprehensive analysis and comparison of ICT investment behavior before, during and after the crisis is not possible. A second limitation is that the data for our study come only from one country, Greece, which, however, offers an appropriate national context for investigating factors affecting firms' behavior in crises, because of the severity and the length of the economic crisis in this country. A third limitation is that we have dealt with factors affecting firms' behavior in economic crisis with respect to only one type of firms' investment: ICT investment (which, however, is highly important for firms' efficiency, innovation, performance, and competitiveness). Therefore, further similar research is required concerning different types of firms' investment, in various national contexts (with different levels of economic and technological development), using data from several years (before, during and after the economic crisis).

Notes

1. However, it is worth-mentioning a case study by Leidner et al. (2003), based on interviews with 20 CIOs, which identified four approaches to managing ICT during the crisis of 2000–02 that differ in their time horizon (short-term or long-term) as well as in the degree of changing the preexisting ICT plan. Also, Loukis et al. (2021) analyze the ICT-related behavior of the five "system-relevant" Greek banks in the first years 2010–2014 of the Greek economic crisis.
2. Bertschek et al. (2017) find in a study based on German firm data that during the crisis in 2008 and 2009 the decrease of productivity was lower in the ICT-intensive firms than in the non-ICT intensive ones, presumably because the former were more successful in introducing ICT-based process innovations during this period than the latter.
3. Due to missing values for several variables we could use only 306 observations for the econometric part.
4. The structure of a representative sample of the Swiss economy served as reference for the final composition of our sample by sector: manufacturing: 40.2% of all firms in the sample; modern services: 30.0% of service firms (Arvanitis et al., 2014, p. 24).

Disclosure statement

No potential conflict of interest was reported by the authors.

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appendix

Table A1. Sampling procedure: composition in % of original and intermediate sample by industry in %.

Industry	Original sample	Intermediate sample
Food, beverage, tobacco	37.1	34.3
Textiles, clothing, leather	8.6	11.3
Wood processing	1.0	0.9
Paper	3.8	4.4
Printing	5.2	5.1
Chemicals	8.3	11.1
Plastics, rubber	5.6	4.5
Glass, stone, clay	5.7	5.7
Metal, metal working	7.8	11.0
Machinery, vehicles	4.1	3.4
Electrical machinery, electronics	3.5	3.0
Other manufacturing (furniture, etc.)	5.9	1.4
Energy, water	3.4	3.8
Manufacturing	*30.7*	*27.7*
Construction	*5.7*	*11.2*
Trade	65.4	66.5
Hotels, catering	13.1	6.6
Transport, telecommunication	8.7	15.7
Computer services	2.1	2.0
Business services	10.7	9.5
Services	*63.6*	*61.1*
Total	*N = 6429*	*N = 3308*

Table A2. Used sample's composition by industry and firm size class.

Industry	N	%
Food, beverage, tobacco	46	12.7
Textiles, clothing, leather	7	1.9
Wood processing	3	0.8
Paper	8	2.2
Printing	6	1.7
Chemicals	19	5.2
Plastics, rubber	8	2.2
Glass, stone, clay	4	1.1
Metal, metal working	7	1.9
Machinery, vehicles	8	2.2
Electrical machinery, electronics	10	2.8
Other manufacturing (furniture, etc.)	12	3.3
Energy, water	8	2.2
Manufacturing	*146*	*40.2*
Construction	*34*	*9.4*
Trade	63	17.3
Hotels, catering	23	6.3
Transport, telecommunication	16	4.3
Computer services	21	5.8
Business services	60	16.5
Services	*183*	*50.4*
Small: up to 49 employees	191	52.6
Medium-sized: 50 to 249 employees	131	36.1
Large: 250 employees and more	41	11.3
Total	*363*	*100.0*

Table A3. Definition of variables.

Variable	Definition
Dependent variables	
ICT_INVEX	Impact of crisis 2009–2014 on *overall* ICT investment expenditures (six-level ordinal variable; 1: "increase;" 6: "very large decrease")
ICT_INVEX1	Impact of crisis 2009–2014 on *hardware* investment (six-level ordinal variable; 1: "increase;" 6: "very large decrease")
ICT_INVEX2	Impact of crisis 2009–2014 on *software* investment (six-level ordinal variable; 1: "increase;" 6: "very large decrease")
ICT_INVEX3	Impact of crisis 2009–2014 on *ICT training* (six-level ordinal variable; 1: "increase;" 6: "very large decrease")
ICT_INVEX4:	Impact of crisis 2009–2014 on *ICT consulting* (six-level ordinal variable; 1: "increase;" 6: "very large decrease")
Independent variables	
ICT-related resource endowment	
R&D	R&D activities in the period 2012–2014 (binary variable; yes/no)
HQUAL	Share of employees with tertiary-level education 2014
ICT_PERS	Share of ICT-specialized personnel 2014
ORG	Use of new forms of workplace organization such as teams, job rotation, decentralization of decision making, etc. (binary variable; yes/no)
ICT_INFRA	Average intensity of use of the following five main ICT enterprise applications: ERP, CRM, SCM, Business Intelligence/Business Analytics, Collaboration Support system (each of these use intensities is measured on a five-point Likert scale; 1: "no use;" 5: "very intensive use")
CLOUD	Use of cloud computing (binary variable; yes/no)
ICT-related capabilities	
ICT_CAP_1	Capability for rapid implementation of changes of the applications of existing information systems to cover specific firm needs (five-level ordinal variable; 1: "(available) to a very small extent/not at all;" 5: "(available) to a very large extent")
ICT_CAP_2	Capability for rapid development of new ICT applications to cover specific firm need (five-level ordinal variable; 1: "(available) to a very small extent/not at all;" 5: "(available) to a very large extent")
ICT_CAP_3	Capability for rapid realization of interconnection and integration of existing ICT applications inside the firm (five-level ordinal variable; 1: "(available) to a very small extent/not at all;" 5: "(available) to a very large extent")
ICT_CAP_4	Capability for good cooperation and information exchange between ICT personnel and ICT users inside the firm (five-level ordinal variable; 1: "(available) to a very small extent/not at all;" 5: "(available) to a very large extent")
ICT_CAP_5	Capability for good cooperation and information exchange with ICT suppliers of hardware, software and networks) (five-level ordinal variable; 1: "(available) to a very small extent/not at all;" 5: "(available) to a very large extent")
ICT_CAP_6	Capability for developing ICT strategic plans that are connected with overall firm strategy (ICT business alignment) (five-level ordinal variable; 1: "(available) to a very small extent/not at all;" 5: "(available) to a very large extent")
Overall internal problems	
INTER_PRO	Average of the scores on a five-point Likert scale of the following three single factors that could be considered as sources/causes of firm problems in the period 2009–2014: insufficient cost control; over-investment in equipment, buildings and storage capacity; over-expansion by takeovers, mergers, etc. (1: "not important;" 5: "very important")
Competition conditions	
P_COMPET	Intensity of price competition at the product market; five-level ordinal variable (five-level ordinal variable; 1: "very small;" 5: "very strong")
NP_COMPET	Intensity of non-price competition at the product market; five-level ordinal variable: (five-level ordinal variable; 1: "very small;" 5: "very strong")
OBSOL	Average of the scores on a five-point Likert scale of the two single factors concerning the extent to which firm's products and services quickly become obsolete/outdated, and also their technologies change quickly (1: "not at all;" 5: "to a very large extent")
Liquidity conditions	
LIQUIDITY	Average of the scores on a five-point Likert scale for the following three single factors that could be considered as sources/causes of firm problems in the period 2009–2014: decrease of credit limits by banks; by suppliers; decrease of paying willingness of customers (1: 'not relevant; 5: "very relevant")
Macroeconomic conditions	
MACRO	Average of the scores on a five-point Likert scale for the following four single factors that could be considered as sources/causes of firm problems in the period 2009–2014: decrease of domestic private demand, demand of the public sector; of foreign demand; decrease of product and service prices (1: 'not relevant; 5: "very relevant")
LAGE	Natural logarithm of firm age (2015 minus foundation year)
Medium-sized	50 to 149 employees; binary variable
Large	250 and more variables: binary variable

Note: The capability variables ICT_CAP_1 to ICT_CAP_ICT_6 are ordinal variables measured on five-point Likert scale (1: "(available) to a very small extent/not at all;" 5: "(available) to a very large extent").

Table A4. Tests for joint effects.

For equation in column (7) in Table 2:
Coeff(R&D)+coeff(HQUAL)+ coeff(ORG) = 0;
Chi2 = 0.34; Prob>Chi2 = 0.561;
Coeff(ICT_PERS)+ coeff(ICT_INFRA)+coeff(CLOUD) = 0;
Chi2 = 2.07; Prob>Chi2 = 0.151;
Coeff(R&D)+coeff(HQUAL)+coeff(ICT_PERS)+coeff(ORG)+coeff(ICT_INFRA)+coeff(CLOUD) = 0;
Chi2 = 0.89; Prob>Chi2 = 0.347;
Coeff(P_COMPET)+coeff(NP_COMPET)+coeff(OBSOL) = 0;
Chi2 = 2.52; Prob> Chi2 = 0.112;
Coeff(ICT_CAP_1)+ … +coeff(ICT_CAP_6) = 0;
Chi2 = 2.73; Prob>Chi2 = 0.098.

Note: coeff.: coefficients of the respective variables in Table 2.