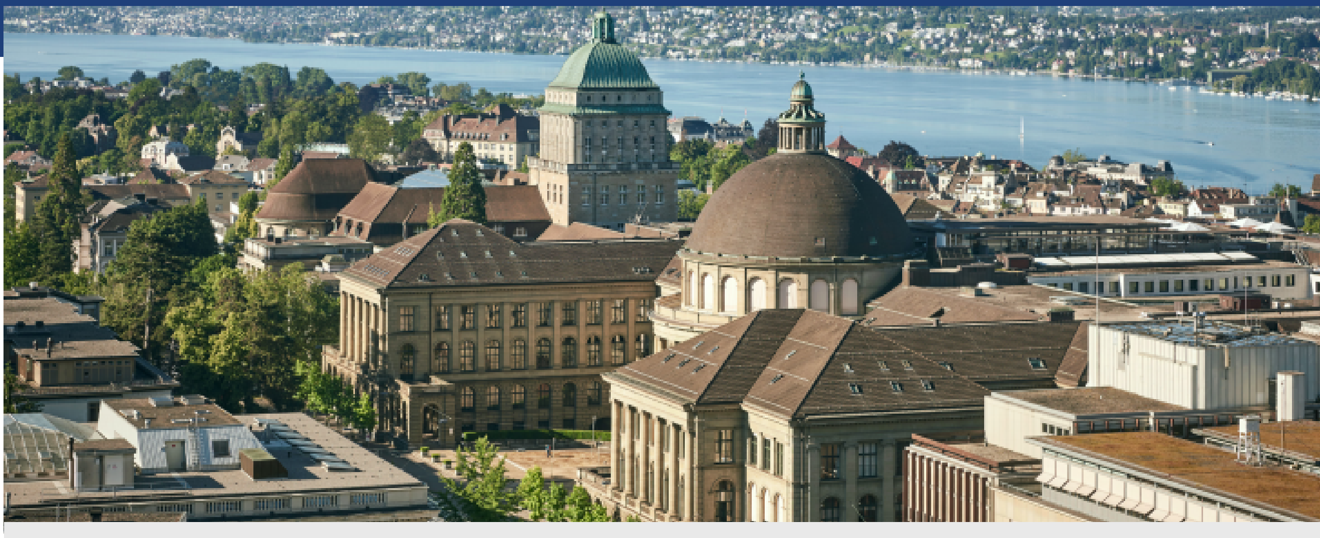

Did the Reduction of ICT Investment Due to the 2008 Economic Crisis Affect the Innovation Performance of Firms? An Exploratory Analysis Based on Firm Data for the European Glass, Ceramics, and Cement Industry

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Abstract

In this paper we investigate empirically, first, the characteristics of the firms that reduced their ICT investment due to the 2008 crisis, particularly the firms' ICT-related characteristics in terms of ICT budget, skills and applications used. The analysis of the ICT characteristics that may influence the likelihood of having reduced ICT investment as a consequence of the crisis is primarily explorative, thus driven by available data and economic intuition. The second research question we examine empirically refers to the possibility that an economic crisis could affect innovation performance through the ICT investment channel. In connection with this, it is also interesting to analyze the ICT characteristics that are associated with ICT-enabled innovation performance. This is the third research question of this paper. Our study is based on firm data from the glass/ceramics/cement industry in six European countries.

We find that ICT-related crisis vulnerability correlates positively with decreasing ICT budgets (pro-cyclical investment behaviour), the existence of skill deficits in ICT, the awareness of and interest in novel ICT applications that presumably request much additional ICT investment, the exposure to strong price competition and the strong presence in international markets, in which activities have significantly decreased due to the crisis. Further, statistically significant negative relationship between ICT-enabled product innovation and crisis vulnerability (pro-cyclical behaviour) is found only for new products or services that contain ICT components, and are therefore directly affected by crisis-related decreasing product demand. Employment of specialized ICT personnel, ICT outsourcing (only for process innovation), competition (only for product innovation), and the use of some ICT applications specific to the kind of innovation pursued are ICT characteristics that positively correlate with ICT-enabled innovation.

JEL Classification: O31,

Key words: economic crisis, information and communication technologies (ICT), innovation, ICT-enabled innovation

1. Introduction

The financial and economic crisis of 2008 affected negatively investment in general and investment in ICT was not left unchanged (Rojko et al. 2011, Keeley and Love 2010, OECD 2009). World ICT spending fell by around 4% in 2009 (OECD 2010). Nevertheless, the decrease of ICT investment has been lower than that of GDP worldwide so that the ratio of ICT investment to GDP has increased. The 2009 decline of world spending in ICT is not as large in current US dollars as in 2001-02, owing to growth in non-OECD economies and the introduction of new products (OECD 2010). Worldwide, about 57% of the 2009 ICT spending was on communication services and hardware, 21% on computer services, 13% on computer hardware and 9% on software. About 76% of world ICT spending is in the OECD countries (OECD 2010).

The theoretical expectation for the impact of crisis on ICT investment is qualitatively the same as for all other kinds of investment. The main idea is that independent of the source of financing the general investment propensity decreases in periods of economic recession. Firms are confronted with demand uncertainty that makes investment more risky than in 'normal' or boom periods. Demand uncertainty forces firms to a pro-cyclical behaviour. Particularly in the innovation literature, an alternative approach is discussed that leads to an anti-cyclical investment behavior. According to the opportunity costs approach, in a booming economy it is expected that costs for labour and other input factors for R&D activities are high, while in recessions these costs are low (Rafferty and Funk 2004). Hence, opportunity costs are lower in recessions and firms would benefit if they could shift resources to R&D activities. It is then an empirical issue which situation for which investment type prevails.

We are interested to investigate, first, the characteristics of the firms that reduced their ICT investment due to the 2008 crisis, particularly the firms' ICT-related characteristics mainly in terms of the ICT budget, skills and applications used. The analysis of the ICT characteristics that may influence the likelihood of a reduction of ICT investment as a consequence of the crisis is primarily explorative, thus driven by available data and economic intuition.

ICT use is according to existing empirical literature an important driver of innovation activities and performance (Kleis et al. 2012). As a consequence, we expect that the drop of ICT investment during the crisis might cause a negative effect on specific ICT-enabled innovation performance. This would be the ICT-related effect of crisis on innovation. Thus, the second research question we want to examine empirically refers to the possibility that an economic crisis could affect innovation performance through the ICT investment channel (i.e. by leading to lower ICT investment). In connection with this, it is also interesting to analyze the ICT characteristics that are associated with ICT-enabled innovation performance. This is the third research question we want to pursue in this paper.

Our study is based on firm data from the glass/ceramics/cement industry in six European countries. The glass, ceramics and cement industry is an important supplier of the construction sector, and as a consequence, an industry that depends primarily on domestic demand. In this sense, the state of affairs in this industry reflects the situation of a country's part of the economy that is oriented to domestic demand.

We find that ICT-related crisis vulnerability correlates positively with decreasing ICT budgets (pro-cyclical investment behaviour), the existence of skill deficits in ICT, the awareness of and interest in novell ICT applications that presumably request much additional ICT investment, the exposure to strong price competition and the strong presence in international markets, in which activities have significantly decreased due to the crisis. Further, statistically significant negative relationship between ICT-enabled product innovation and crisis vulnerability (pro-cyclical behaviour) is found only for new products or services that contain ICT components, and are therefore directly affected by crisis-related decreasing product demand. Employment of specialized ICT personnel, ICT outsourcing (only for process innovation), competition (only for product innovation), and the use of some ICT applications specific to the kind of innovation pursued are ICT characteristics that positively correlate with ICT-enabled innovation.

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 research field.

The paper is structured as follows: section 2 presents the conceptual background, related literature and the research hypotheses. Section 3 discusses the data. In section 4 is the models' specification presented, while in section 5 econometric issues are discussed. In section 6 the results are presented and discussed. Section 7 concludes the paper.

2. Conceptual background, related literature, and research hypotheses

ICT Investment, Innovation Investment and Crisis

The theoretical expectation for the impact on ICT investment is qualitatively the same as for all other kinds of investment. The main idea is that independent of the source of financing the general investment propensity decreases in periods of economic recession. Firms are confronted with demand uncertainty that makes investment more risky than in 'normal' or boom periods. Decreasing demand limits also internal financing of investment by past revenues. Uncertain economic perspectives reduce also the willingness of banks and other financial intermediaries to finance firms' investment projects. Of course, not all kinds of investment 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 and Stegmaier 2013; Geroski and Gregg 1997). Further, not all types of firms bear the same risk, with small firms being confronted with more difficulties to finance investments in recession than large firms due to credit rationing by financial intermediates (for the theoretical background see, e.g., Stiglitz and Weiss 1981 for investment in general; Goodacre and Tonks 1995 for investment in innovation). So in general, we expect that economic crisis negatively affects ICT investment. To our knowledge, there are no studies dealing with question of the impact of economic crisis on ICT investment.[1] As a consequence, it is not a priori clear which ICT characteristics explain a firm's ICT-related behavior in an economic crisis (see hypothesis 1a to 1c below). The analysis of the ICT characteristics that may influence the likelihood of having reduced ICT investment as a consequence of the crisis is primarily explorative, thus driven by available data and economic intuition.

There is some theoretical consent (see, e.g., Barlevy 2007) and some empirical evidence (see, e.g., Quyang 2011a and Guellec and Ioannidis 1999) that R&D investment expenditures of firms, the most important input for innovation, are pro-cyclical, i.e. they are increasing in the business upswing and they are decreasing in the business downturn. However, there are also some theoretical arguments as well as some anecdotic evidence that firms show an anti-cyclical R&D investment behaviour. In order to explain pro- or anti-cyclical R&D behaviour we have to take into account two diverging forces, the demand aspect (see Filippetti and Archibugi 2011) and the opportunity costs aspect (Rafferty and Funk 2004).[2] Since R&D investments are predominantly financed through the cash-flow of a firm, which is expected to fluctuate pro-cyclically with demand, we would expect a pro-cyclical R&D investment behaviour as well. However, in a booming economy, it is expected that costs for labour and other input factors for R&D activities are higher, while in recessions these costs are clearly lower. Hence, opportunity costs are lower in recessions and firms would benefit if they could shift resources to R&D activities. If the opportunity cost aspect prevails, we would expect anticyclical behaviour; firms would make use of lower production costs in recessions and would intensify their R&D investments. Since empirical evidence supports mostly pro-cyclical behaviour we concentrate here on the hypothesis of pro-cyclical behaviour with respect to innovation (see hypothesis 2 below).

ICT and Innovation

There are many ways through which the use of ICT can contribute to firms' innovation. According to Kleis et al. (2012) this can happen through three main channels. The first channel goes through the improvement of the management of the knowledge used in the innovation process. Information technology enables an efficient storage and a high accessibility of this knowledge throughout an enterprise. Internal networks, e-mail systems, and electronic databases all facilitate the transfer of knowledge and the communication between innovation participants inside the firm. Second, ICT enables a more efficient cooperation in innovation with external partners. Information technology facilitates the exchange of information with

[1] However, there is a paper which is worth mentioning: In a case study, Leidner et al. (2003) found based on interviews with 20 CIOs that firms reacted both pro- and anti-cyclically to the crisis of 2000-02 depending on their short-term or long-term time-horizon.

[2] For a more detailed discussion of these approaches see Arvanitis and Woerter (2014).

external partners who are located far away from the focal firm. This is quite useful, as the creation of new knowledge through collaboration with other firms has become more and more important in the last twenty years (Enkel et al. 2009). Third, ICT contributes directly to the innovation production in several ways. Kleis et al. (2012) identified three main stages of the innovation process, for which the application of ICT has proved to be useful. First, the stage of the generation of ideas for new products can benefit from information systems (e.g., Customer Relationship Management (CRM)) that enable a firm to collect and analyse extensively customers' communication and transaction data, and identify through them needs that can be covered by new products or significant modifications of existing products. Second, ICT enables the development of efficient design capabilities for new products. For example, technologies such as computer-aided design (CAD) and computer-aided manufacturing (CAM) help to digitize a new product's design, make it available throughout the innovation process. Third, ICT helps integrate design and production systems, so that errors of information transfer and translation are reduced and, as a consequence, the efficiency of this last stage of the innovation process is increased (Tapscot et al., 2000; Brynjolfsson and Saunders, 2010). In sum, we expect a positive impact of ICT through these three channels on innovation performance (see hypothesis 3 below).

Research hypotheses

Based on the above discussion of literature, we postulate a series of hypotheses:

Hypothesis 1a: The ICT characteristics that refer to ICT inputs (budget, human capital) and the ICT infrastructure (as represented by the ICT applications used by a firm) are *jointly positively* correlated with the ICT-related crisis vulnerability.

Hypothesis 1b: The ICT characteristics that refer to ICT inputs (budget, human capital) and the ICT infrastructure (as represented by the ICT applications used by a firm) are *jointly negatively* correlated with the ICT-related crisis vulnerability.

Hypothesis 1c: The ICT characteristics that refer to ICT inputs (budget, human capital) and the ICT infrastructure (as represented by the ICT applications used by a firm) are not at all correlated with the ICT-related crisis vulnerability.

Hypothesis 2: *ICT-enabled* innovation performance measures are *negatively* correlated with the extent of a firm's vulnerability with respect to ICT-related crisis. Thus, we expect *pro-cyclical* behaviour with respect to ICT-enabled innovation.

Hypothesis 3: The ICT characteristics that refer to ICT inputs (budget, human capital) and the ICT infrastructure (as represented by the ICT applications used by a firm) are *jointly positively* associated with *ICT-enabled* innovation performance measures.

3. Data

The data used in this study come from the e-Business Survey 2009 of the European Union. The survey focused on companies from the glass, ceramics and cement industries of six EU countries: Germany, Spain, France, Italy, United Kingdom and Poland, and consisted of 676 telephone interviews with ICT decision-makers, using computer-aided telephone interview (CATI) technology.

The questionnaire contained about 90 questions which were structured into eight modules. The survey population was defined as companies with at least 10 employees which used computers, were active within the national territory of one of the above-mentioned six countries covered, and which had their primary business activity in the glass, ceramics or cement industry as specified by NACE Rev. 2 Groups 23.1-6. The survey was carried out as an enterprise survey: data collection and reporting focus on the enterprise, defined as a business organization (legal unit) with one or more establishments. The sample drawn was a stratified random sample of companies from the population in each of the six countries, with the objective of fulfilling minimum strata with respect to company size-bands per country-sector cell (see 'Annex I: Methodology Report' in Sectoral e-Business Watch 2009). Pilot interviews prior to the regular fieldwork were conducted with about 15 companies in Germany in February 2009, in order to test the questionnaire (structure, comprehensibility of questions, average interview length). The response rate, i.e. the number of completed interviews divided by the net sample of contacts established with eligible hospitals/enterprises, was typically about 15-20%, with, however, big differences in some of the countries. The dataset that was used for the econometric estimates contained 676 observations. Table A.1 in the Appendix shows the composition of the dataset by country, sub-sector and firm size class, Table A.2 contains descriptive statistics for the observations used in the empirical work. Tables A.3 shows the correlations between the model variables.

Table 1 contains information on the impact of economic crisis on ICT investment plans or projects by sub-sector, country and firm size class. Crisis vulnerability has been rather uniformly distributed among the firms of the three subsectors: about 41% (glass) to 48% (ceramics) firms reported an impact of crisis on their ICT investment plants. Small firms have been less crisis vulnerable than middle-sized and large firms, presumably because larger firm are stronger dependent than small firms on exports that have decreased significantly as a consequence of the crisis. Significant differences exist among countries: about 26% reported a crisis impact in Germany, while the respective figure for Poland was about 57%. The figures for the other countries lie somewhere between these two extremes. Thus, the crisis vulnerability in the glass/ceramics/cement sector reflects to a large extent the overall vulnerability of economy at country level. However, the majority of firms in these sectors, about 50% (ceramics) to 59% (glass) of them, was not affected by the crisis with respect to ICT investment, thus showing a considerable crisis resistance. This could be interpreted as a hint that ICT-related investment behaviour in these sectors shows no cyclicality or even is anti-cyclical (see the discussion in section 2). We concentrate here to those firms (40% to 50% of all firms) that were affected by the crisis and showed a pro-cyclical behaviour as to ICT investment.

4. Model specification

Explanation of the extent of ICT-related crisis vulnerability (crisis equation)

Dependent variable. We construct a binary variable (ICT_CRISIS) based on the following question of the e-Business Survey 2009: "Has the economic crisis an impact on your ICT investment plans or on ICT projects?" (see Table 2). The variable is codified as follows: 0: no impact; 1: yes, "*no* ICT or e-business projects were cancelled or significantly downsized", or yes, "ICT or e-business projects were cancelled or significantly downsized".[3]

Independent variables. We distinguish three groups of variables (see Table 2 for more details):

ICT inputs: We use four variables, two related to the availability of ICT-specific human resources (ICT_personnel; ICT_skill deficits; both of them are binary variables), one concerning the available financial resources (ICT_ budget; a three-level ordinal variable), and one referring to the existence of ICT-outsourcing, meant as use of external ICT rservices as a measure to reduce ICT-related costs.

ICT infrastructure: The e-commerce is an important ICT application that serves to manage the firm functions as consumer (e-procurement E_P) as well as supplier of goods and services (e-sales E_S). Both e-commerce variables are six-level ordinal variables. In the Survey information is also available for a wide spectrum of other standard ICT applications, such as Enterprise Resource Planning (ERP), Supply Chain Management (SCM), Supplier Relationship Management (SRM) as well as Customer Relationship Management CRM). Further applications (CAD, CAM) refer to manufacturing activities in the more narrow sense. We construct separate variables for firms that use specific applications by way of 'software-as-a-service' (SAAS), and also for firms for which one or more of the following novel technologies are of relevance (in the sense that firms are aware of and have interest in them): service-oriented architectures, web 2.0 applications, data warehouses, and mobile services such as mobile commerce and remote access technologies (ICT_NEWTECH). Since firms' ICT infrastructure is composed of all these applications, the respective binary variables are included in our model.

Market conditions: We distinguish three dimensions of competition at the product market: price competition (PCOMP), quality competition (QCOMP) and customer service competition (SCOMP). The respective measures of the importance of these types of competition for the firms are three-level ordinal variables.

[3] We constructed also a three-level ordinal variable showed similar results as the binary one. We prefer to show here the estimates for the simpler binary variable.

Firms with intensive price competition in their main markets are likely to have difficulties to finance their ICT activities, since their price-cost margins are expected to be low. In good business times they are expected to have less problems to finance ICT investment. Hence, their investment behaviour is expected to be pro-cyclical, in our case meaning that a positive correlation is expected with the ICT crisis vulnerability variable. We expect that the competition pressure with respect to quality and customer service would be less strong than price competition in a crisis period. In this sense, firms that are exposed stronger to non-price competition are expected to be less crisis-vulnerable with respect to ICT.

Other firm characteristics: Controls are inserted in the estimation equation for firm size, sub-sector, country, strong export-orientation (EXPORT), and also the firm being part of a multinational corporation (INTER). At first glance, we would expect larger firms and firms belonging to multinational corporations to be less crisis-vulnerable with respect to ICT than smaller firms because of the availability of more financial resources that help them to survive through a crisis. The descriptive data in Table 1 show that it is the other way around, small firms being less crisis vulnerable than middle-sized and large firms, presumably because (i) larger firm are stronger dependent than small firms on exports that have decreased significantly as a consequence of the crisis, and (ii) small firms make less ICT investments, usually limited to the absolutely necessary ones, so there are less opportunities for ICT investment due to the crisis.

The economic crisis that started in 2008 has led to a decrease of world trade volume, thus of exports. Export-oriented firms have been stronger exposed to this particular crisis component than firms that primarily cover the domestic demand. Thus, we expect that export-oriented firms of the glass, ceramics and cement sector, which is primarily oriented to domestic demand, would be particularly affected by the crisis.

As already mentioned, the analysis of the ICT characteristics that may influence the likelihood of having reduced ICT investment as a consequence of the crisis is primarily explorative, thus driven by available data and economic intuition (see *hypothesis 1a* to *1c*). A formal expression of the crisis equation is as follows:

$$ICT\_CRISIS_i = a_0 + a_1\, ICT\_budget_i + a_2\, ICT\_outsourcing_i + a_3\, ICT\_personnel_i + a_4\, ICT\_skills\_deficits_i + a_5\, E\_P_i + a_6\, E\_S_i + a_7\, ERP_i + a_8\, SCM_i + a_9\, CRM_i + a_{10}\, CAD + a_{11}\, CRM + a_{12}\, SAAS + a_{13}\, ICT\_NEWTECH + a_{14}\, PCOMP + a_{15}\, QCOMP + a_{16}\, SCOMP_i + a_{17}\, INTER_i + a_{18}\, EXPORT_i + a_{19}\, Medium\text{-}sized_i + a_{20}\, Large_i + sector\ controls + country\ controls + e_i \quad (1)$$

(for firm i)

Effect of ICT-related crisis vulnerability and ICT characteristics on ICT-enabled innovation performance (innovation equations)

Dependent variables. We exploit the available information in the survey concerning the introduction of product and process innovations in the 12 months period before the survey in 2009 that are closely related to ICT, and distinguish six different measures of ICT-related product and process innovation concerning: (a) new products or services that contain *ICT components*; (b) new products or services for which ICT has played an important part in their *R&D process*; (c) new products and services for which ICT has played an important part in their *market launch*; (d) new processes that are supported by ICT; (e) new processes for which ICT has played an important part in their *design*; (f) new processes for which ICT has played an important part in their *implementation* (see Table 2 for the definition of these variables). These variables allow a differentiated measurement of the specific contribution of ICT to product and process innovation.

Independent variables. We use the same vector of variables as in the crisis equation, with the exception of the variable *ICT_skills_deficits*, while in addition we include the variable ICT_CRISIS. We expect a *negative* correlation of this crisis variable with all six measures for *ICT-enabled* innovation (*hypothesis 2*). According to *hypothesis 3* we expect a *joint positive* effect of the three groups of variables representing ICT inputs and ICT infrastructure, respectively, but we do not dispose of more detailed hypotheses regarding the effects of each single variable in the abovementioned groups of ICT variables. Finally, we expect a joint positive effect for the three competition variables and a positive effect for firm size according to standard economic theory and empirical evidence (see, e.g., Cohen 2010 for a comprehensive survey of studies on innovation economics at the firm level). Formally expressed our innovation equations are:

$$[INNOPD\_ICTx;\ INNOPC\_ICTx]_i = a_0 + a_1\ ICT\_CRISIS + a_2\ ICT\_budget_i + a_3\ ICT\_outsourcing_i + a_4\ ICT\_personnel_i + a_5\ E\_P_i + a_6\ E\_S_i + a_7\ ERP_i + a_8\ SCM_i + a_9\ CRM_i + a_{10}\ CAD + a_{11}\ CRM + a_{12}\ SAAS + a_{13}\ ICT\_NEWTECH + a_{14}\ PCOMP + a_{15}\ QCOMP + a_{16}\ SCOMP_i + a_{17}\ INTER_i + a_{18}\ EXPORT_i + a_{19}\ Medium\text{-}sized_i + a_{20}\ Large_i + sector\ controls + country\ controls + e_i \qquad (2)$$

where x: 1, 2, 3; (for firm i)

5. Econometric issues

Multivariate probit

Activities directed to product innovation and those aiming at process innovation are closely related (see, e.g., Athey and Schmutzler 1995 for a theoretical justification of this close complementary relationship; Kraft 1990; and Rouvinen 2002 for empirical evidence). In order to take this interdependence into account we estimated a trivariate model for INNOPD_ICT1, INNOPD_ICT2 and INNOPD_ICT3 as well as a trivariate model for INNOPC_ICT1, INNOPC_ICT2 and INNOPC_ICT3. The correlation coefficients (values between 0.5 and 0.9; see Table 4) that were estimated for the trivariate models show that the choice of a trivariate model is econometrically justified. Due to technical difficulties we could not estimate a multivariate model for all six variables for ICT-enabled product and process innovation. However, this is not a big problem because the interdependence between the three ICT-enabled product innovation variables and between the three ICT-enabled process innovation variables is considerably larger than between product and process innovation as the correlation coefficients of additional estimations not shown here demonstrate.

We applied the STATA-procedure 'mvprobit', which estimates M-equation probit models, by the method of maximum simulated likelihood (MSL). The variance-covariance matrix of the cross-equation error terms has values of 1 on the leading diagonal, and the off-diagonal elements are correlations to be estimated (rhoji = rhoij, and rhoii = 1, for all i = 1,...,M). The procedure uses the Geweke-Hajivassiliou-Keane (GHK) simulator to evaluate the M-dimensional Normal integrals in the likelihood function. For each observation, a likelihood contribution is calculated for each replication, and the simulated likelihood contribution is the average of the values derived from all the replications. The simulated likelihood function for the sample as a whole is then maximized using standard methods (maximum likelihood in this case). For a brief description of the GHK smooth recursive simulator, see Greene (2003, 931-933), who also provides references to the literature.

Probit

For the binary variable ICT_CRISIS we used a maximum likelihood probit model (STATA-procedure 'probit').

Causality

Due to the cross-section character of our data, both the left-hand and the right-hand variables refer to the same time period. As a consequence, our estimates of both the crisis and the innovation equations have to be seen primarily as an extensive analysis of the correlations between the independent variables (that are considered as structural characteristics that change only slowly over time) and the ICT-related crisis and ICT-enabled innovation indicators, respectively. Nevertheless, some robust regularities come out, which if interpreted in view of our hypotheses presented in section 2 could possibly indicate the direction of causal links.

However, the possible distorting effect of the crisis variable, which is explicitly considered to be an endogenous variable in equation (1), in the innovation equations summarized in (2) has to be taken into account. To this end, we applied the procedure developed by Rivers and Vuong (1988) to test the exogeneity of the crisis variable in the innovation equations. We calculated the residual (predicted value minus effective value of variable ICT_CRISIS) of equation (1) and inserted it as a further right-hand variable in the innovation equations summarized in (2). As instrument we used the variable *ICT_skill_deficits*, which is significantly correlated with CRISIS, but not with any of the ICT-enabled innovation variables, and is not included in the specification of (2). Lack of ICT skills could at least partially be a problem due to limited supply of ICT-skilled personnel in some countries, thus exogenous to firms. The coefficients of the residual variable were not statistically significant at the 10% test level in any of the innovation equations. As a consequence, the estimates in Table 4 and 5 are based on the original crisis variable. The detailed results of the exogeneity tests are available upon request.

Other issues

Multicollinearity is not an issue in our estimations as shown in the correlation matrix in Table A.3 in the appendix. Marginal effects were not estimated because 14 out of 21 right-hand variables in the equations (1) and (2) are dummy variables and the rest 7 are ordinal variables.

6. Results

Crisis equation

ICT-related crisis vulnerability correlates positively with decreasing ICT budgets (pro-cyclical investment behaviour), the existence of skill deficits in ICT (as they reduce the value that can be generated for the firm from new ICT investments), the degree of perceived relevance of novel ICT applications (ICT_NEWTECH) that presumably request much additional ICT investment, the exposure to strong price competition (PCOMP) and the strong presence in international markets (EXPORT), in which activities have significantly decreased due to the crisis (Table 3).

Larger firms are stronger export-oriented and as a consequence stronger exposed to (price) competition than the smaller ones. This explains the stronger impact of crisis on larger firms in the descriptive data in Table 1, even if the coefficient of the dummy for large firms is not significantly positive in Table 3, presumably because the two variables PCOMP and EXPORT, respectively, have captured most of the firm size effect. None of the coefficients of the variables for the standard ICT applications is statistically significant, thus indicating that firms' ICT technology portfolio is not related to crisis vulnerability. These findings seem to support partially hypothesis 1b, with respect to ICT inputs (as lower levels of ICT budget and skill deficits increase ICT-related crisis vulnerability), and partially hypothesis 1c with respect to ICT infrastructure.

The positive sign for ICT_NEWTECH can be interpreted as a hint that firms that are more aware of the relevance of new technologies, and as a consequence of the need for much additional investment for exploiting them, tend to cancel or significantly downsize planned ICT projects (that concern mainly 'traditional' technologies) in order to fund the introduction in the future of new technologies, thinking that they have to exploit them to improve their ICT infrastructure as a reaction to crisis.

Innovation equations: ICT-enabled innovation performance

Product innovation

The relationship between ICT-enabled product innovation and ICT-related crisis vulnerability is negative for all three examined categories of product innovationthe former, but only for INNOPD_ICT1 (new products containing ICT components) is this relationship statistically significant (column 1 in Table 4). The explanation for this negative effect is straightforward: the stronger the crisis impact on ICT investment, the less ICT-enabled innovation can be generated, particularly in the case of products and services that direct contain ICT components. This finding is in accordance with hypothesis 2 (pro-cyclical behaviour with respect to ICT-enabled innovation). However, the statistically significant negative relationship is found only for new products or services that contain ICT components, and are therefore *directly* affected by decreasing product demand. No significant relationship could be found for the *indirect* influence of ICT on product innovation through the R&D or marketing channel (see the definition of the three types of ICT-enabled product innovation in Table 2).

ICT budget change due to the crisis is not relevant for all three types of ICT-enabled product innovation, presumably because the main effect of reduced financing of ICT is captured by the crisis variable. ICT outsourcing is positively correlated for innovation activities generating new products that contain ICT components. A possible explanation for this effect could be that ICT components may be cheaper acquired from specialized firms, so that production of such components can be outsourced. Having specialized ICT personnel is significantly positively correlated with all three categories of ICT-enabled product innovation. Also, for all these three types of innovation is the degree of perceived relevance of novel ICT technologies (ICT_NEWTECH) positively correlated with innovation; this indicates that firms generating ICT-enabled product innovations have higher awareness of and show higher interest in novel ICT, in order to exploit them for further product innovations. With respect to standard ICT applications, e-procurement and CAD seem to be of relevance for the first two categories of product innovation (ICT components in products; ICT in R&D processes). Standard ICT applications are of no importance for ICT-enabled innovation that is related to the market launching of new products (column 3 in Table 4). On the whole, some variables for ICT inputs as well as ICT infrastructure show jointly positive effects on ICT-related product innovation, thus support hypothesis 3.

Price competition is not relevant for ICT-enabled product innovation. The two relevant dimensions of competition are quality competition (for INNOD_ICT1) and customer service competition (for INNOPD_ICT2), respectively. This finding is in accordance with our theoretical expectation. Belonging to a group of firms and being active at international markets are not important for ICT-enabled product innovation. A further interesting result refers to the absence of a size effect (with the exception of a positive effect for medium-sized firms in the estimates for INNOPD_ICT2): the likelihood of ICT-enabled innovation in the glass/ceramics/cement industry appears to be independent of firm size, innovation activities are not concentrated in large firms, as it is often the case in other industries.

Process innovation

The relationship between ICT-enabled process innovation and ICT-related crisis vulnerability is not statistically significant for all three examined categories of ICT enablement in process innovation (Table 5). The decrease of ICT investment due to the crisis is not correlated with the introduction of ICT-enabled process innovation. This is not in accordance with the hypothesis 2 for pro-cyclical behaviour with respect to process innovation. Presumably, firms continued improving their production processes in the crisis period using the existing ICT resources in innovative ways and more efficiently than before.

There is a common pattern for all three examined categories of ICT-enabled process innovation: availability of ICT-specialized personnel and ICT outsourcing play an important role for all three of them. Presumably, the ICT needed for process innovation is less firm-specific than for product innovation, so that outsourcing becomes a valid alternative to the development of firm-specific ICT-applications inside the firm. The perceived interest in novel technologies is also positively associated with ICT-enabled process innovation; this indicates that firms introducing ICT-enabled process innovations have higher awareness of and show higher interest in novel ICT, in order to exploit them for further process innovations. For new process that are supported in general by ICT (INNOPC_ICT1) standard applications such as “Supplier Relationship Management” (SRM) and “Computer Aided-Design” (CAD) are also needed. On the whole, variables for ICT inputs as well as ICT infrastructure show jointly positive effects also on ICT-related process innovation, providing support for hypothesis 3.

Competition does not seem to be of any relevance for all three types of ICT-enabled process innovation, which is not what we would theoretically expect especially with respect to price competition. Larger firms show a significantly stronger tendency to ICT-enabled process innovation than medium-sized firms, and medium-sized firms show a stronger tendency than small firms. Thus, for process innovation, a size effect is found; bigger firm size leads to more complex processes, with numerous steps and involved employees, so there is stronger motivation for and benefit from exploiting the capabilities offered by ICT in order to generate process innovations.

7. Summary and Conclusions

Crisis vulnerability

We have found that ICT-related crisis vulnerability correlates positively with decreasing ICT budgets (pro-cyclical investment behaviour), the existence of skill deficits in ICT, the perceived relevance of the potential use of new ICT applications (ICT_NEWTECH) that presumably request much additional ICT investment, the exposure to strong price competition, and the strong presence in international markets, in which activities have significantly decreased due to the crisis. Larger firms are stronger export-oriented and as a consequence stronger exposed to (price) competition than smaller ones. This explains the stronger impact of crisis on larger firms in the descriptive data. None of the coefficients of the variables for the standard ICT applications is statistically significant, thus indicating that firms' ICT technology portfolio is not related to crisis vulnerability. These findings seem to support partially hypothesis 1b, with respect to ICT inputs (as lower levels of ICT budget and skill deficits increase ICT-related crisis vulnerability), and partially hypothesis 1c with respect to ICT infrastructure. These are the main insights of the exploratory part of our investigation.

Crisis and innovation performance

Statistically significant negative relationship between ICT-enabled innovation and ICT-related crisis vulnerability is found only for new products or services that contain ICT components, and are therefore *directly* affected by crisis-related decreasing product demand. Only for this type of ICT-related innovation appears pro-cyclical behaviour to be dominant. No significant relationship could be found for the *indirect* influence of ICT on product innovation through the R&D or marketing channel. Furthermore, the decrease of ICT investment is not correlated with the introduction of ICT-enabled process innovation. This is not in accordance with the hypothesis 2 for pro-cyclical behaviour with respect to process innovation. Presumably, firms continued to improve their production processes in the crisis period using their existing ICT resources in innovative ways and more efficiently than before. On the whole, hypothesis 2 for pro-cyclical behaviour receives only limited support.

ICT characteristics and innovation performance

Human resources in form of ICT-specialized personnel are important for all six categories of ICT-enabled innovation. For four out of six examined innovation categories, the ICT outsourcing, reflecting a strategy of efficiency increase of the use of ICT resources, is also relevant. The ICT technology portfolio characterized by a series of ICT applications is only partially important for innovation performance, thus hypothesis 3 receives only partial support from our findings. The use of some single ICT applications, such as E_P and CAD correlate positively with two out of three product innovation categories, while CAD is important also for one process innovation category. A common innovation-relevant characteristic for all six examined ICT-enabled innovation categories is the awareness of and interest in novel technologies, such as service-oriented architectures, web 2.0 applications, data warehouse and data mining, and mobile services such mobile commerce and remote access technologies.

The discussion about the pro-cyclical or anti-cyclical character of different categories of investment that are associated with high risks and high sunk costs, e.g., R&D investment, or are of specific relevance for innovation output, e.g., ICT investment, is important not only for management but also for policy-making. For example, anti-cyclical investment behaviour with respect to ICT might mitigate negative implications of the cyclical movement of the economy both at firm level (e.g., high costs for search and recruitment of high-qualified ICT) and at economy level (e.g., deterioration of ICT infrastructure). However, we would need data for several sectors of the economy in order to be able to better understand the mechanisms behind cyclical behaviour of ICT investment.

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TABLES:

Table 1: Impact of economic crisis on ICT investment plans or ICT projects

	No	Yes, no cancelling / downsizing ICT projects	Yes, cancelling / downsizing ICT projects	N total
Sector				
Glass	59.1	15.1	25.8	159
Ceramics	51.6	23.2	25.2	155
Cement	58.5	20.2	21.3	362
Country				
Germany	74.4	8.9	16.7	180
Spain	44.0	25.6	30.4	125
France	65.0	14.0	21.0	86
Italy	47.5	21.8	30.7	101
United Kingdom	64.0	21.5	14.1	64
Poland	43.4	30.8	25.8	120
Firm size (number of employees)				
10 – 49 employees	65.1	19.2	15.7	364
50 – 249 employees	51.9	19.3	28.8	264
250 employees and more	36.1	26.7	37.2	86

Table 2: Definition of variables

Variables	Definition
Dependent variables	
ICT_CRISIS	Has the economic crisis an impact on your ICT investment plans or on ICT projects? Binary variable: 1: yes, no ICT or e-business projects were cancelled or significantly downsized or yes, ICT or e-business projects were cancelled or significantly downsized; 0: No impact
INNOPD_ICT1	The new products or services have *ICT components*; binary variable: 1: yes; 0: no
INNOPD_ICT2	ICT has played an important part in the *R&D process* which led to the new products or services; binary variable: 1: yes; 0: no
INNOPD_ICT3	ICT has played an important part in the *market launch* of the new products or services; binary variable: 1: yes; 0: no
INNOPC_ICT1	The new processes are supported by ICT; binary variable: 1: yes; 0: no
INNOPC_ICT2	ICT has played an important part in the *process design*; binary variable: 1: yes; 0: no
INNOPC_ICT3	ICT has played an important part in the *implementation* of the new processes; binary variable: 1: yes; 0: no
Independent variables	
ICT_budget	Change of ICT budget (covering primarily current variable costs and depreciation): 3-level ordinal variable: 0: decrease; 1: no change; 2: increase
ICT_personnel	Employment of ICT practitioners; yes/no
ICT_skill deficits	Have the employees problems because of insufficient computer skills? yes/no
E_P	Use of *e-procurement*: 6-level ordinal variable: 0: no e-procurement; 1: less than 5% of purchases; 2: 5-10%; 3: 11-25%; 4: 26-50%; 5: 50% and more
E_S	Use of *e-sales*: 6-level ordinal variable: 0: no e-sales; 1: less than 5% of sales; 2: 5-10%; 3: 11-25%; 4: 26-50%; 5: 50% and more
ERP	Use of 'Enterprise Resource Planning'; yes/no
SCM	Use of 'Supply Chain Management'; yes/no
SRM	Use of 'Supplier Relationship Management'; yes/no
CRM	Use of 'Customer Relationship Management'; yes/no
CAD	'Computer Aided Design'; yes/no
CAM	'Computer Aided Manufacturing'; yes/no
SAAS	Use of specific applications by way of 'software-as-a-service', which is licensed for use on line; yes/no
ICT_NEWTECH	Relevance for the company of: service-oriented architectures; web 2.0 applications; data warehouses and data mining; mobile services such as mobile commerce and remote access technologies

PCOMP	Importance of *price competition* in the main market; 3-level ordinal variable: 0: not important; 1: quite important; 2: very important
QCOMP	Importance of *quality competition* in the main market; 3-level ordinal variable: 0: not important; 1: quite important; 2: very important
SCOMP	Importance of *customer service competition* in the main market; 3-level ordinal variable: 0: not important; 1: quite important; 2: very important
INTER	Part of a *multinational* enterprise; yes/no
EXPORT	*International* market as most important sales market; yes/no
Medium-sized	50 to 249 employees
Large	250 employees and more
Sector dummies	Ceramics, cement (reference: glass)
Country dummies	France, Italy, Poland, Spain, United Kingdom (reference: Germany)

Table 3: Ordered probit estimates for ICT_CRISIS

	ICT_CRISIS
ICT inputs	
ICT_budget	-0.718***
	(0.118)
ICT_outsourcing	0.084
	(0.149)
ICT_personnel	0.149
	(0.136)
ICT_skill deficits	0.314***
	(0.119)
ICT infrastructure	
E_P	0.042
	(0.054)
E_S	-0.022
	(0.060)
ERP	0.081
	(0.143)
SCM	0.136
	(0.185)
SRM	0.122
	(0.201)
CRM	-0.100
	(0.152)
CAD	0.103
	(0.121)
CAM	-0.051
	(0.153)
SAAS	0.069
	(0.151)
ICT_NEWTECH	0.169***
	(0.041)
Market conditions	
PCOMP	0.295***
	(0.101)
QCOMP	-0.169
	(0.117)
SCOMP	0.090
	(0.091)
Other firm characteristics	
INTER	0.205
	(0.174)
EXPORT	0.244*
	(0.149)
Medium-sized	-0.036
	(0.130)

Large	0.078
	(0.205)
Sector dummies (2)	Yes
Country dummies (5)	Yes
Const.	-1.114***
	(0.372)
N	676
Wald chi2	173.7***
Pseudo-R2	0.192

Note: Heteroskedasticity-robust standard errors in brackets; ***. **, * denote statistical significance at the 1%, 5% and 10% test level resp.; reference for ‘medium-sized’, ‘large’: ‘small’.

Table 4: Trivariate probit estimates for INNOPD_ICT1, INNOPD_ICT2 and INNOPD_ICT3

	INNOPD_ICT1	INNOPD_ICT2	INNOPD_ICT3
ICT_CRISIS	-0.546***	-0.017	-0.064
	(0.217)	(0.199)	(0.207)
ICT inputs			
ICT_budget	0.052	0.007	-0.014
	(0.169)	(0.170)	(0.170)
ICT_outsourcing	0.423**	-0.100	0.029
	(0.218)	(0.213)	(0.199)
ICT_personnel	0.657***	0.710***	0.534***
	(0.218)	(0.210)	(0.209)
ICT infrastructure			
E_P	0.200***	0.231***	0.029
	(0.081)	(0.087)	(0.079)
E_S	0.045	-0.068	-0.015
	(0.089)	(0.096)	(0.083)
ERP	-0.116	-0.319	0.085
	(0.257)	(0.233)	(0.233)
SCM	0.187	0.012	-0.026
	(0.313)	(0.297)	(0.264)
SRM	0.210	-0.187	-0.085
	(0.312)	(0.280)	(0.272)
CRM	0.299	0.152	0.228
	(0.234)	(0.226)	(0.214)
CAD	0.506**	0.421**	-0.117
	(0.210)	(0.201)	(0.193)
CAM	0.302	-0.228	-0.233
	(0.241)	(0.250)	(0.228)
SAAS	-0.308	0.255	0.022
	(0.251)	(0.246)	(0.225)
ICT_NEWTECH	0.150**	0.129**	0.175***
	(0.063)	(0.059)	(0.059)
Market conditions			
PCOMP	0.281	0.119	0.162
	(0.170)	(0.157)	(0.148)
QCOMP	-0.054	0.370*	0.219
	(0.200)	(0.219)	(0.180)
SCOMP	0.366**	-0.207	-0.052
	(0.165)	(0.157)	(0.142)
Other firm characteristics			
INTER	-0.138	0.185	-0.165
	(0.251)	(0.262)	(0.243)
EXPORT	0.009	-0.012	0.275
	(0.286)	(0.251)	(0.234)
Medium-sized	0.396	0.348	0.140

	(0.245)	(0.218)	(0.213)
Large	0.148	0.438	-0.488
	(0.331)	(0.300)	(0.289)
Sector dummies (2)	Yes	Yes	Yes
Country dummies (5)	Yes	Yes	Yes
Const.	-3.457***	-2.622***	-1.365***
	(0.635)	(0.658)	(0.463)
N		247	
Wald chi2		229.8***	
Rho21		0.672**	
Rho31		0.510***	
Rho32		0.795***	
Wald chi2 test of rho = 0		100.0***	

Note: Heteroskedasticity-robust standard errors in brackets; ***. **, * denote statistical Significance at the 1%, 5% and 10% test level resp.; reference for ‘medium-sized’, ‘large’: ‘small’.

Table 5: Trivariate probit estimates for INNOPC_ICT1, INNOPC_ICT2 and INNOPC_ICT3

	INNOPC_ICT1	INNOPC_ICT2	INNOPC_ICT3
ICT_CRISIS	0.128	-0.099	-0.126
	(0.194)	(0.197)	(0.187)
ICT inputs			
ICT_budget	0.021	0.035	0.170
	(0.158)	(0.166)	(0.171)
ICT_outsourcing	0.387**	0.757***	0.827***
	(0.196)	(0.201)	(0.219)
ICT_personnel	0.403**	0.650***	0.560***
	(0.191)	(0.185)	(0.189)
ICT infrastructure			
E_P	0.065	0.091	0.060
	(0.084)	(0.083)	(0.084)
E_S	0.100	0.077	0.048
	(0.095)	(0.086)	(0.093)
ERP	0.364	0.169	0.164
	(0.228)	(0.237)	(0.236)
SCM	-0.058	-0.059	0.124
	(0.321)	(0.334)	(0.345)
SRM	0.602*	0.073	0.232
	(0.336)	(0.320)	(0.343)
CRM	0.112	-0.188	0.122
	(0.220)	(0.213)	(0.228)
CAD	0.380**	0.066	0.030
	(0.190)	(0.196)	(0.188)
CAM	0.098	-0.005	-0.030
	(0.242)	(0.229)	(0.221)
SAAS	-0.059	-0.213	-0.383
	(0.251)	(0.250)	(0.258)
ICT_NEWTECH	0.134**	0.317***	0.332***
	(0.059)	(0.069)	(0.064)
Market conditions			
PCOMP	-0.091	-0.001	-0.086
	(0.151)	(0.147)	(0.139)
QCOMP	-0.054	-0.094	0.052
	(0.210)	(0.200)	(0.173)
SCOMP	-0.196	-0.130	-0.216
	(0.135)	(0.161)	(0.147)
Other firm characteristics			
INTER	0.431	0.316	0.212
	(0.291)	(0.250)	(0.247)
EXPORT	-0.076	-0.168	-0.111
	(0.225)	(0.228)	(0.233)
Medium-sized	0.656***	0.528***	0.508***

	(0.196)	(0.205)	(0.204)
Large	0.339	0.659**	0.642**
	(0.287)	(0.306)	(0.302)
Sector dummies (2)	Yes	Yes	Yes
Country dummies (4)	Yes	Yes	Yes
Const.	-0.552	-1.040*	-1.073**
	(0.565)	(0.566)	(0.537)
N		291	
Wald chi2		295.7***	
Rho21		0.763***	
Rho31		0.831***	
Rho32		0.912***	
Wald chi2 test of rho = 0		180.3***	

Note: Heteroskedasticity-robust standard errors in brackets; ***. **, * denote statistical Significance at the 1, 5 and 10% test level resp.; reference for ‘medium-sized’, ‘large’: ‘small’.

APPENDIX:

Table A.1: European glass, ceramics and cement industry: composition of the dataset by country, sub-sector and size class

		Glass	Ceramics	Cement	Total	
		N	N	N	N	%
Country						
Germany		43	43	94	180	26.6
Spain		17	29	79	125	18.5
France		22	22	42	86	12.7
Italy		28	19	54	101	14.9
United Kingdom		24	17	23	64	9.5
Poland		25	25	70	120	17.8
Firm size (number of employees)						
10 – 49 employees		84	76	204	364	53.9
50 – 249 employees		53	54	119	226	33.4
250 employees and more		22	25	39	86	12.7
Total	N	159	155	362	676	100
	%	23.5	22.9	53.6	100	

Table A.2: Descriptive statistics

Variable	N	Mean	Std. Dev.	Min	Max
CRISIS	676	0.661	0.830	0	1
INNOPD	676	0.365	0.482	0	1
INNOPC	676	0.430	0.496	0	1
INNOPD_ICT1	247	0.364	0.482	0	1
INNOPD_ICT2	247	0.441	0.498	0	1
INNOPD_ICT3	247	0.506	0.501	0	1
INNOPC_ICT1	291	0.632	0.483	0	1
INNOPC_ICT2	291	0.543	0.499	0	1
INNOPC_ICT3	291	0.595	0.492	0	1
ICT_budget	676	0.951	0.489	0	2
ICT_outsourcing	676	0.164	0.371	0	1
ICT_personnel	676	0.265	0.442	0	1
ICT_skill deficits	676	0.464	0.499	0	1
E_P	676	0.938	1.156	0	5
E_S	676	0.383	0.969	0	5
ERP	676	0.320	0.467	0	1
SCM	676	0.135	0.342	0	1
SRM	676	0.121	0.327	0	1
CRM	676	0.235	0.424	0	1
CAD	676	0.444	0.497	0	1
CAM	676	0.180	0.385	0	1
SAAS	676	0.172	0.377	0	1
ICT_NEWTECH	676	1.649	1.733	0	7
PCOMP	676	1.654	0.577	0	2
QCOMP	676	1.791	0.461	0	2
SCOMP	676	1.525	0.663	0	2
INTER	676	0.138	0.345	0	1
EXPORT	676	0.200	0.400	0	1
Medium-sized	676	0.334	0.472	0	1
Large	676	0.229	0.421	0	1

Table A.3: Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1 ICT_CRISIS	1.00																			
2 ICT_budget	-0.24	1.00																		
3 ICT_outsourcing	0.11	-0.05	1.00																	
4 ICT_personnel	0.19	0.03	0.18	1.00																
5 ICT_skill_deficits	0.16	-0.03	0.12	0.20	1.00															
6 E_P	0.09	0.07	0.14	0.12	0.17	1.00														
7 E_S	0.05	-0.01	0.06	0.11	-0.00	0.28	1.00													
8 ERP	0.21	-0.10	0.09	0.27	0.020	0.26	0.10	1.00												
9 SCM	0.16	-0.01	0.12	0.16	0.03	0.15	0.14	0.26	1.00											
10 CRM	0.14	-0.09	0.06	0.17	0.08	0.18	0.06	0.34	0.29	1.00										
11 CAD	0.12	-0.00	0.08	0.14	0.21	0.13	0.04	0.25	0.10	0.15	1.00									
12 CAM	0.08	-0.02	0.03	0.13	0.06	0.06	0.04	0.23	0.23	0.19	0.25	1.00								
13 SAAS	0.07	0.03	0.06	-0.01	-0.02	0.14	0.06	0.01	0.18	0.04	0.04	0.03	1.00							
14 ICT_NEWTECH	0.32	-0.01	0.11	0.35	0.23	0.24	0.11	0.43	0.27	0.34	0.30	0.19	0.13	1.00						
15 PCOMP	0.07	0.05	-0.00	-0.04	0.03	-0.00	0.01	-0.06	0.03	0.04	-0.02	-0.05	0.04	-0.02	1.00					
16 QCOMP	-0.02	0.02	0.00	0.05	0.00	0.08	0.05	0.00	0.03	0.06	0.11	0.03	0.02	0.09	0.13	1.00				
17 SCOMP	0.00	0.01	-0.07	0.01	-0.18	-0.00	0.09	-0.11	-0.06	0.08	-0.05	-0.00	0.02	-0.04	0.10	0.24	1.00			
18 INTER	0.16	-0.12	0.12	0.23	0.18	0.21	0.01	0.27	0.08	0.21	0.14	0.11	0.02	0.25	-0.01	0.03	-0.02	1.00		
19 EXPORT	0.07	-0.03	0.09	0.05	0.09	0.19	0.12	0.13	0.12	0.05	0.10	0.04	-0.04	0.06	-0.11	0.11	-0.01	0.10	1.00	
20 Medium-sized	0.07	0.01	0.05	0.04	0.14	0.12	-0.03	0.22	0.08	0.10	0.13	0.03	0.04	0.17	0.03	0.00	-0.05	0.06	0.07	1.00
21 Large	0.16	-0.05	0.11	0.34	0.15	0.11	0.10	0.35	0.12	0.12	0.17	0.12	-0.03	0.28	-0.06	-0.00	-0.15	0.26	0.15	-0.27