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Industry-University R&D Collaboration and Innovative Performance of Greek Manufacturing Firms in Times of Crisis: Do Interactions of Knowledge Flows and Knowledge Stocks Matter?

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Abstract

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engaged in innovative activities. We also find that the beneficial effects of industry-university collaborations in terms of innovation are more pronounced in the midst of the crisis rather than after the crisis outbreak. Finally, non-exporting firms and firms with employees of lower educational level are more likely to benefit from collaborations with universities compared to exporting firms and firms with employees of higher educational level. In other words, firms with lower levels of knowledge stocks benefit more in terms of innovation from the development of knowledge flows with universities.

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Abstract

Using panel probit regressions and a unique data survey for the 524 largest Greek manufacturing firms, we analyze the links between firm innovation and collaboration with universities in the crisis years 2011 and 2013, taking also into account possible interactions between knowledge flows and knowledge stocks. We find that industry-university R&D collaborations play an important role in shaping firm innovation taking the form of an inverted U. When firms develop training programmes for their employees, pursue differentiation strategies and become larger their innovative chances improve. On the contrary, we show that the crisis deepening can reduce the probability of firms to be engaged in innovative activities. We also find that the beneficial effects of industry-university collaborations in terms of innovation are more pronounced in the midst of the crisis rather than in the beginning of the crisis. Finally, young, non-exporting firms with employees of lower educational level are more likely to benefit from collaborations with universities compared to old, exporting firms with employees of higher educational level. In other words, firms with lower levels of knowledge stocks benefit more in terms of innovation from the development of knowledge flows with universities.

Keywords: Industry-University R&D Collaboration; Innovation; Knowledge Flows; Knowledge Stocks; Economic Crisis

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1. Introduction

The recent economic crisis that burst in 2008 has created a far more turbulent and difficult environment for Greek economy and Greek firms. The combination of long standing, systemic weaknesses and shortcomings of its National System of Innovation along with poorly managed public finances, has created a hectic macroeconomic, but also business, environment. Over the six-year period 2008-2013, Greece lost about 25% of its gross value added, and unemployment increased to the level of 27%. Moreover, there are clear signs that the production potential of the economy was also adversely affected during the specific period, although, at the current juncture, it is difficult to quantify the degree of the damage. When examining closely the recent history of the local production system and its performance, it clearly appears that the significant growth period of 1994-2007 was not driven by innovation or knowledge-intensive production. Instead of focusing on industrial and productive structural change, firms preferred to focus mainly on internal markets, since prices were satisfactory and a promising turnover could be rather easily achieved. Hence, efforts for innovation were weakened, thus affecting the overall innovation performance of the Greek productive system. At this point in time, many more voices stress the urgent need for an "innovating out of the crisis" growth strategy based on the knowledge production and use in order for the Greek economy to track a sustainable and dynamic recovery path.

In this respect, the idea that firms' capabilities to assess and exploit information and knowledge outside their boundaries has a central role to play in innovative performance is an emerging one in the last years (e.g. Caloghirou, Kastelli, & Tsakanikas, 2004). In this line, several innovation studies explicitly recognize that firms need to be able to identify, absorb and use knowledge possessed by external actors in order to enrich firms with technological competencies and internal resources (Enkel, Gassmann, & Chesbrough, 2009; Gassmann, 2006; Hsieh & Tidd, 2012; Huizingh, 2011). In this way, it seems that many forms of valuable commercialized knowledge are constantly developed by actors and organizations external to the firm in a rapid pace and volume (Vanhaverbeke, Van de Vrande, & Cloodt, 2008). Cassiman & Veugelers, (2006) provide evidence and argumentation that firm innovation strategies tend to be more effective when they are characterized by the existence of any complementarity between internal knowledge investment and

external knowledge acquisition. Also, several studies demonstrate the significant role that existing knowledge stocks play in shaping innovativeness (e.g. Lee, 2010; Wu & Shanley, 2009), while some others highlight the beneficial effects of university knowledge flows on firm innovation (Agrawal & Henderson, 2002; Agrawal, 2006; Henard & McFadyen, 2006; Monjon & Waelbroeck, 2003; Tether, 2002).

These studies, however, largely neglect the combined role of knowledge stocks and university knowledge flows on firms' product innovation. Such evidence is important for understanding the mechanism by which the mix or the balance between exploiting knowledge stocks and exploring knowledge flows may determine a firm's innovative performance. Also, it can better inform policy makers, especially in the context of the Greek economy where public and private financial resources for research and innovation are scarce implying thus the necessity for the effective combination of knowledge flows and knowledge stocks. Streamlining the research question to the more generic concepts of knowledge flows and stocks we articulate a broader question in strategic innovation: how does the interaction between stocks and flows affect innovative performance of manufacturing firms?

Empirical evidence on this issue remains generally scarce, while recently only a very limited number of recent works have attempted to set research questions on the role of interactions between knowledge flows and knowledge stocks but within a completely different base and dimension. In particular, Al-Laham, Tzabbar, & Amburgey (2011) examine whether the stock of knowledge affects in a different way the rate of innovation, when the firm exhibits high or low levels of knowledge flows. They use human and social capital in order to measure knowledge stocks, while knowledge flows are captured by alliances and recently hired scientists. The authors demonstrate that the effect of knowledge flows on innovation becomes weaker as the time passes, but this attrition can be decelerated when the knowledge stocks are refreshed. In addition, the pioneer work of Roper & Hewitt-Dundas, (2015) examines the role of knowledge stocks, using as metrics the cumulative number of successful patent applications made by the firm, in shaping innovation activity per se and in conjunction with in-house R&D capacity and innovation partnering.

The present paper puts differently this discussion, by exploring whether the flows of knowledge have a similar or a differentiated effect on the rate of innovation, when the firm has high levels of knowledge stocks as when it has low levels of

knowledge stocks. Following this line of thinking, we attempt to explore whether the effect of knowledge flows on innovation depends on the level of stocks. Hence, this paper contributes to the burgeoning literature on knowledge flows and the way they interact with knowledge stocks, particularly relevant to innovation output, explaining in which circumstances university-industry collaborations raise the possibility of product innovation. In this respect, the primary purpose of this paper is to examine whether and in which way university knowledge flows have a significant role to play in shaping firm innovation in times of crisis taking into account the level of knowledge stocks that firms exhibit in terms of their exporting activity, age and the educational attainment of their employees. In order to do that we use field research data collected from 524 of the largest Greek manufacturing firms in two waves for the years 2011 and 2013.

The rest of the paper is organized as follows: First, we provide a brief review of the literature, and next, we describe the survey data and the methodology used for this study as well as the methodology used for the analysis. After reporting and discussing the results, we conclude and provide some policy implications in the Greek context.

2. Literature Review

A firm's ability to access and absorb new knowledge, catch up with technological progress and try to constantly innovate is crucial for its survival and growth. The importance of innovation as a characteristic that helps in creating and maintaining economic value and sustainable competitive advantage has been largely acknowledged from the very early work of Schumpeter (1934) and many others that followed. However, technological systems and progress have become more complicated since then, implying that various disciplines need to be fused and integrated in order to produce not only radical but also marginal innovation, while at the same time competition has intensified and many new entrants from emerging economies are joining a global competitive battlefield for innovation. Structured R&D labs and generally internal mechanisms were the main source for innovative efforts at least till the late 80'(Vonortas, 1997). But nowadays it is increasingly difficult for firms to innovate based solely on their own portfolio of resources. It is firms' external linkages and networks that also play an important role, especially in adverse times, while firms need to develop those dynamic capabilities and absorptive capacity that

will allow them to take advantage of such research relationships (Powell, Koput, & Smith-Doerr, 1996). Nevertheless, both internal capabilities and openness towards knowledge sharing are important for upgrading innovative performance (Caloghirou et al., 2004).

Theoretical and empirical research in the field of innovation economics has shown that this type of networking with external actors and knowledge sources can have a positive influence on firms' innovation performance (Baum, Calabrese, & Silverman, 2000; Belussi, Sammarra, & Sedita, 2010; Brioschi, Brioschi, & Cainelli, 2002; Rothaermel & Deeds, 2006). Industry-science relations positively affect innovation performance through the use of scientific knowledge (Becheikh, Landry, & Amara, 2006; Feller, 1990; Freel, 2003; Fukugawa, 2006; Kang & Lee, 2008; Kline & Rosenberg, 1986; Mansfield, 1995; Mowery, 1990; Nieto & Santamaría, 2007; Romijn & Albaladejo, 2002; Rosenberg & Nelson, 1994). Collaboration with universities and research institutes may spur the creation of radical, next-generation innovations (Belderbos, Carree, & Lokshin, 2004) or new transformations of existing technologies (Archibugi & Coco, 2004; Arvanitis, Kubli, & Woerter, 2008; Drejer & Jørgensen, 2005). The positive impact of research collaborations on innovation derives from the ability of partners to share technological knowledge, take advantage of scale economies in research, provide crucial intellectual input and leverage complementary assets (Powell et al., 1996; D. Teece, 1992). But of course the success of this process builds also on the relative absorptive capacity of each participant to leverage such external complementary resources.

Incoming flows of external knowledge infuse knowledge and practices into the firm and foster the development of new knowledge (R Henderson & Cockburn, 1994; Kogut & Zander, 1992). These streams of knowledge serve as mechanisms that prevent firms from becoming inert—that is, rigid, narrow, and simple—because of the obsolescence of their knowledge base (Leonard, 1992; Levinthal & March, 1993). Streams of new knowledge also help firms develop new capabilities and prevent them from falling into a competency trap (March, 1991). Because firms prefer to learn in areas in which they already have expertise (Levinthal & Myatt, 1994; Leonard-Barton, 1995), they also tend to confine themselves to a limited set of knowledge domains and have difficulty responding to developments outside these areas. This

phenomenon reflects the fact that firms sometimes keep on using a set of routines and capabilities that may be far from optimal (Levitt & March, 1988).

Building on the theory of the knowledge-based view of the firm we explore the interdependencies between University- firm collaboration (we consider this as a knowledge flow mechanism), and different types of knowledge stocks: educational level of employees, exporting activity and age of the firm. The knowledge-based view argues that the heterogeneous knowledge bases and capabilities among firms are the main determinants of their different performance at the market level. Hence, firms not only use their different knowledge bases and capabilities in developing knowledge but also have different access to external sources of knowledge. Dierickx & Cool (1989) have described knowledge stocks as those accumulated knowledge assets which are internal to the firm while knowledge flows represent knowledge streams into various parts of the firm which gradually are transformed into stocks of knowledge. Firms with higher knowledge stocks than their rivals can favorably position themselves in their industries (McEvily & Chakravarthy, 2002).

One further underlying element of our analysis that is tempting nowadays is the effect of the economic crisis. During adverse times, skills, knowledge assets may decay faster than usual. What will determine a firm's ability to innovate is how knowledge stocks and flows are affected by constraints that arise during a crisis.

2.1 Knowledge flows for firm innovation: R&D collaboration with universities

It is widely known that universities constitute one of the key enablers that firms can use to increase their knowledge base. The linkages between firms and academia as a knowledge transfer mechanism is not only an academic issue in economics and management studies, but it is a significant policy item in the science and technology policy agenda of a number of developed and developing countries (Balconi, Breschi, & Lissoni, 2004). Collaboration with universities and research institutes facilitates access to national and international knowledge networks (Okubo & Sjöberg, 2000) and may support the hiring and selection of talented graduates and doctoral researchers which can create the conditions for some impactful innovations (Thursby & Thursby, 2002).

Empirical evidence on the effect of firms' R&D collaboration with Universities on innovation is flourishing. Agrawal (2006) has found that when firms

involve university based inventors in commercializing an invention, they tend to be more successful than when they do not. Tether (2002) suggests that collaboration with universities is generally aimed at radical breakthrough product innovations that may open up entire new markets or market segments. Other studies point on the nature of universities as venues for a wider range of ideas, extensive breadth of new knowledge and multidisciplinary perspectives than most companies, which allows them to deliver on multidisciplinary research initiatives (e.g. Henard & McFadyen, 2006).

From a firm's perspective, collaborations with universities are imperative for exploiting scientific knowledge and novel ideas (Audretsch, Leyden, & Link, 2013; Caloghirou, Tsakanikas, & Vonortas, 2001; Subramanian, Lim, & Soh, 2013). More science based linkages increase the probability of obtaining useful external knowledge that can be combined with the firm's internal knowledge to produce innovation (Leiponen & Helfat, 2010). In addition, empirical evidence suggests that knowledge gained from different types of collaborations generates complementarities between external linkages with firms' internal R&D (Roper, Du, & Love, 2008). It has been certified that collaboration between industry and universities is useful in reducing the cost of R&D, decentralizing risks, and promoting these organizations to share resources and attain complementary capability. Networking can be critical in order to attain economies of scale and/or to integrate diverse skills, technologies and competencies (Mancinelli & Mazzanti, 2007).

Apart from benefits, R&D collaborations with universities also imply transaction costs accounting for searching and coordinating joint research contracts (Gulati & Singh, 1998). Changing internal R&D structure "*from discovery generation as the primary activity to systems design and integration as the key function*" (Chesbrough, 2005) is also required in case of excess reliance on collaborative research which creates further expenses. Although a moderate level of external R&D activities facilitates firms to capture and exploit knowledge, a very large scale of collaborative R&D activities do not necessarily lead to increased innovation gains. Prior research has stressed how the imbalanced sourcing of R&D activities in favor of external knowledge acquisition, erodes innovative performance (Berchicci, 2013). Thus, this strand of literature suggests an inverted U relationship between R&D collaboration of firms with universities and innovation output.

In the next sub-sections we present the other factors which are of primary interest in the specific context that we have set in this paper, since they capture the economic downturn and the knowledge stocks.

2.2 Economic crisis and innovation

When an economy is in a recession cycle, the general economic conditions worsen business opportunities become rarer, financial constraints arise, credit expansion smooths out, while we may observe losses in human capital that may decide to turn elsewhere for more promising careers. But what happens in terms of innovative attempts? Procyclical arguments suggest that firms tend to consider innovation expenditures as more "*luxurious*" and thus reduce innovation activities due to limited resources, but also due to a perceived higher risk compared to more "*baseline activities*". According to Block & Sandner, (2009) the financial crisis can lead to a severe "*funding gap*" in the financing of technology-intensive and innovative start-ups. On the other hand, countercyclical arguments claim that it is exactly in this period of time that you need to invest in R&D and produce innovation that may support a new competitive advantage. Hence, empirical evidence is rather ambiguous in this issue. Some scholars find a positive relationship between industry downturns and process innovation (Nickell et al., 2001). Also, Paunov, (2012) using firm-level data for 8 countries of Latin America for the years 2008-2009 find that the crisis caused significant innovation project discontinuations possibly related to increased financing constraints. Other scholars and researchers find non-existent associations (McGahan & Silverman, 2001; Saint-Paul, 1993), while others argue that industry fluctuations trigger innovation activities due to diminishing rents of existing activities (Geroski & Walters, 1995).

2.3 Knowledge stocks for innovation: exporting, educational level, and firm age

Exporting

Competing in foreign markets is not an easy task for firms, since it requires not only the development of new products/services but also advanced capabilities in order for them to gain significant market shares. In most cases, ventures that become exporters are able to identify opportunities across borders, they are alert to the chances to combine resources from different national markets and they exploit their competencies with respect to knowledge and networking. Many empirical studies

show that firms enjoy high productivity gains prior to their exporting activity, based on the "*self-selection*" argument (Bernard & Jensen, 1999; Roberts & Tybout, 1997), according to which exporting is mainly explained by better firms selecting in the cross-border markets rather, rejecting thus the learning from exporting hypothesis. For that reason, in this paper exporting has been conceptualized as a knowledge stock variable, rather than a knowledge flow one. Guan & Ma, (2003) and Knight & Cavusgil, (2004) demonstrate that firms achieving to operate in cross-border markets exploit knowledge and internal capabilities, despite the lack of financial capital and tangible resources. Born-global firms tend to be innovative and/or possess unique intangible knowledge-based resources such as management experience in international markets, technological knowledge, and market knowledge. Capabilities related to the exploitation of existing knowledge enable firms to create value and obtain competitive advantage suitable to penetrate abroad (Oviatt & McDougall, 1994; Bloodgood, Sapienza, & Almeida, 1996). The export orientation of a firm would thus be positively correlated with its innovative activity (Roper & Love, 2002). Given the above, this paper considers the exporting activity of a firm as a signal for the existence of a high knowledge stock within the firm.

Education

The educational level of firm's employees has been acknowledged as a factor improving the competitiveness of firms or even as a pre-condition for innovation (Prais, 1995). Through formal education, people develop a number of skills such as intelligence, abstract thinking and a strong interest to find general solutions to problems which are usually associated with high creativity and high probability to perceive innovative business ideas (Koellinger, 2008). Skills obtained through education can exert an important influence on external networking (Lam, 2005). High educational levels can be supposed enabling the detection and management of relevant external knowledge flows (OECD, 2008)[1]. At the same time, knowledge building helps in identifying specific business opportunities in response to a technological change (Shane, 2000). Kang & Lee, (2008) argue that a lack of qualified technical personnel inhibits innovation. Firm-level R&D resources strengthen firm's internal capacity to assimilate and exploit new knowledge and thus

[1] OECD (2008), OECD Science, Technology and Industry Outlook. Paris, OECD.

induce innovation (Bougrain & Haudeville, 2002; W. Cohen & Levinthal, 1990; Lund Vinding, 2006; Parisi, Schiantarelli, & Sembenelli, 2006; Tödtling, Lehner, & Kaufmann, 2009). Hence in our analysis, a high (low) educational level of firm's employees implies also a high (low) level of knowledge stock.

Firm age

Young firms have usually an interesting new idea that can create a niche market or can claim a share of an existing market, but prerequisites under which young firms can be considered as innovative, are not straightforward. Theoretical argumentation provided by the seminal work of Arrow, (1962) suggests that start-ups have strong motives to be highly innovative as a result of the sunk-cost and replacement effects. Many empirical studies provide evidence that firm age is negatively related to innovative attempts (e.g. (Balasubramanian & Lee, 2008; Huergo & Jaumandreu, 2004), despite the fact that start-ups have to filter new knowledge through organizational routines and structures (Henderson & Clark, 1990). However, other studies argue that young firms – independently of their size - do not have developed yet a critical mass of knowledge (Cohen & Levinthal, 1990) and sufficient resources (Teece, 1986), which are necessary for them to innovate. Furthermore, they have not established neither stable relationships with suppliers and clients nor any type of external networking that would allow them to use additional knowledge and expertise in order to innovate (Malerba & Torrisi, 1992; Shan, Walker, & Kogut, 1994). Therefore, we assume that young firms are characterized by low levels of knowledge stocks.

3. Data and Methodology

3.1 Data

The data used in this paper stems from an extensive survey that was carried in more than 2000 of the biggest (in terms of employment) firms in Greece on a national and regional level. The survey was carried out in two waves, one in 2011 and the next one in 2013[2]. Almost 35% of the sample comes from the manufacturing sector which is

[2] The surveys were an integral part of a wider research project that was funded by the Federation of Greek Industries (SEV) and was undertaken by the Foundation for Economic and Industrial Research (FEIR / IOBE) and the Laboratory of Industrial and Energy Economics at the National Technical University of Athens. The primary goal of the project was to set up a data driven mechanism in order to

the subset of firms where we focus in the specific paper. The second wave targeted the same group of firms that had participated in the first wave, so we could build a panel dataset. This process was successful for almost 80% of the sample, while the rest of the sample was replaced by other firms that have borne the same characteristics in terms of employment and sales. However, for the analysis that follows we have selected only the manufacturing firms that participated in both waves. This creates a dataset that contains 524 manufacturing Greek firms.

The empirical instrument of the survey, was a structured questionnaire that includes four major modules on firms' characteristics: a) a "strategy section" with questions on the adopted strategies from the examined firms, b) a "performance section" where analytical information of the firms' investments plans and economic performance was retrieved along with projections for the following years, c) an innovation section where questions about the innovation performance, R&D activity, patent activity and how such efforts were affected by the crisis were included, and d) a final section on the human capital of the firms. The usual firms' demographics were also collected (such as sector of activity, employment, main markets etc.) Hence, the questionnaire allows us to analyze various elements of a business model, the evolution of the innovation process, business decisions related to manufacturing processes, customers and suppliers, markets covered, foreign trade and employment.

3.2 Variables

The dependent variable (*Prod_Innov*) that is used in our analysis is one of the most usual proxies for product innovation. Starting from Schumpeter (1934) about the definition of innovation, we conceptualize product innovation activity as the new product, invention or artifact that is introduced into the market and put into use (Garcia & Calantone, 2002; Schon, 1967). Firms indicated whether they were engaged in new or significantly improved product innovations within the last two years. In the case of a positive answer the dependent variable gets the value of 1 otherwise 0[3]. Independent variables used in our analysis refer to proxies for knowledge stock, knowledge flows, a dummy for the effect of the economic crisis and

map ongoing or emerging structural changes in various production systems, value chains and labor markets, taking also into consideration firms' performance and behavior.

[3] Respondents were also provided with definitions of the product/process innovations drawn from recent Community Innovation Survey (Eurostat 2012), which is mainly based on the Oslo manual (OECD, 2005)

some control variables. R&D collaborations with universities and research centers (*R&D_collab*) is the proxy we use for knowledge flow and represents the firm's effort to access external knowledge sources (Becker & Dietz, 2004; Escribano, Fosfuri, & Tribó, 2009). Firms were asked to estimate on a five-point Likert scale ('not used,' to 'high') the extent to which they had been engaged in R&D collaborations during with such external sources the last couple of years.

In terms of human capital we use the educational level as one of the knowledge stock proxies, since capabilities and especially technological capabilities of a firm are linked and to some extent determined by the skills of its employees (Archibugi & Lundvall, 2002). We measure the education by the share of employees with a long cycle university degree and a short-cycle university degree. Previous studies have used as proxies for measuring human capital in R&D the share of employees with a university education (Muscio, 2007; Romijn & Albaladejo, 2002) or academic degree (Lund Vinding, 2006).

Another human capital factor that is used as independent variable in our analysis is training of the firms' employees. This study adopts a measure modified from (Lyles & Salk, 1996) to measure the extent a firm values learning and care for the development of the professional skills of their employees. Firms responded whether they have used a method of either internal or external training (external seminars, on the job training, etc.). The variable takes the value of 1 if the firm declares that it has trained its employees through any of the above internal or external training methods, and the value of 0 otherwise.

Exporting activity is also used as an independent variable. Relying on the self-selection argument we argue that firms that have exporting capacity have accumulated knowledge that pertains efficiency gains. Exporting is measured by a dichotomous variable that takes the value 1 when the firm is an exporting firm and zero otherwise (E*xporting*).

Finally size and age of a firm may also affect a firm's knowledge base. In the analysis, age is calculated as the natural logarithm of the number of years from the firm's establishment and firm size as the natural logarithm of the total number of employees (Fredrickson, 1984).

The dummy of crisis is a stand-alone factor that we prefer to treat separately since it bears specific characteristics. On the one hand, time passing by erodes the stock of knowledge that has been accumulated. On the other hand, since 2009 Greece has been suffering may be the most severe economic crisis in recent years. Thus a time dummy variable would also serve as a proxy of the impact of crisis. In order to capture the cumulative effect of the crisis, we assume that responses of the 2013 wave are incorporating the crisis to a greater extent compare to the ones in 2011. Therefore the crisis variable is formulated with the value of 0 for the responses of 2011 and the value of 0 for the responses of 2013.

Prior research suggests that there are specific factors that may influence the innovative performance of a firm, which need to be controlled for namely strategic factors, liquidity constraints, competition pressure and training. Relying on Porter's, (1985) generic strategies that firms adopt in order to attain significant and enduring competitive advantage over their rivals we distinguish (i) overall cost leadership, (ii) differentiation strategy. A number of empirical studies have been conducted to test the validity of Porter's generic strategies (Galbraith & Schendel, 1983). The used measures of these strategies have been drawn and adapted from various studies (Dess & Davis, 1984; Danny Miller, 1986; Porter, 1985).

Two variables have been used as different proxies for liquidity constraints. Firms were asked to estimate (on a 1-5 Likert scale), the level of credit crunch conditions they face due to a) banks inability to provide loans, as credit expansion was significantly reduced during the crisis in Greece or b) increased credit risk in their supply chain, as distressed suppliers or clients default on their debts or generally delay payments, which inevitably causes credit crunch pressure even on healthy firms.

Price competition is also used as an independent variable, as firms assessed the extent to which they face such competitive pressures from low cost producers. Finally, it should be stressed that each model includes industry dummies for the manufacturing industries of the sample under examination. More specifically the examined firms are classified in nine sectors[4].

[4] Food and Beverages, Textile, Paper and Publishing, Chemical products, Plastic/ Elastic Industry, Non metallic Industry, Basic metals, Machine and machinery equipment, Furniture, and Rest of manufacturing sectors.

Since our dependent variable is a binary one, and given that the 2 surveys allow to track the same 524 manufacturing firms for the crisis years 2011 and 2013, we apply a panel probit regression to estimate the driving forces of the probability of firms to introduce product innovation. In this context, the linear equation to be estimated at the firm level for the periods 2011 and 2013 can be expressed as follows:

Product Innovation = f {University-Firm R&D Collaboration; Crisis Deepening Dummy; Exporting; Education; Age; Low Cost Strategy; Differentiation Strategy; Liquidity Constraints; Competition Intensity; Training; Size}

where, for the purposes of this study university-firm R&D collaboration is the knowledge flows variable, exporting, education, and age of the firm capture the knowledge stocks variables. Finally, low cost strategy, differentiation strategy, liquidity constraints, competition intensity, training and size are considered as control variables in our analysis.

3.3 Descriptive Statistics

Tables 1, 2 and 3 display some descriptive statistics for the variables used in the study for both waves (wave 1, wave 2). Approximately 60% of the firms in the sample have undertaken a product innovation within the last two years (wave 1, 2011), whereas this falls to less than 50% in wave 2 (2013). So the economic crisis has negatively affected innovative performance, although not to the extent we could expect has worsened during the crisis. Collaboration with Universities is not actually a very common practice for the Greek firms. Only 12.6% responded that they collaborate in R&D projects to a large extent (4 or 5 in a Likert scale). Liquidity constraints are important and have intensified between the two waves (mean wave1=2.85, mean wave 2=3.71). Furthermore it seems that problems across the supply chain are slightly more important than constraints imposed by banks.

"Insert Table 1 about here"

"Insert Table 2 about here"

"Insert Table 3 about here"

With an average number of 165 employees in 2011 and 141 in 2013, the firms in this sample seem fairly large by Greek manufacturing standards. However this is

affected by a very large firm that is included in the sample[5], that is why the median value is 50 to 53 employees. The average age of the firms in the sample is 25 years old (in 2013), but the deviation is large (15 years old). Actually almost 45% of the sample is above 25 years old, whereas only 9% of the distribution is younger firms (less than 10 years old). This is a result of the fact that larger and arguably more established, older firms have a higher probability of being included in the sample, because of the specific focus of the survey to the largest firms in Greece. From the descriptive statistics below we can also infer that Greek firms do not invest much in R&D collaborations. They suffer severely from liquidity constraints having to do with low access to bank financing and difficulties arising from liquidity constraints among companies in the same supply chain. Price based competition is strong but not extremely intense. In terms of training the majority of the largest Greek manufacturing firms invest highly in training, while more than 70% of them export, at least some part of their turnover. More than half of the respondents follow a low cost strategy. On the contrary differentiation strategy does not seem to be a favorite strategic option for the majority of them.

Also, a correlation matrix is provided in Table 4 indicating the absence of any significant correlation among the independent variables, which in turn ensures that the econometric estimates are not biased due to possible multicollinearity problems.

"Insert Table 4 about here"

4. Results and Discussion

The key empirical findings obtained from panel probit regressions are presented in Table 5, where the estimated coefficients are provided along with the standard errors in order to report the significant (or not significant) role of the explanatory variables on the probability for a firm to introduce product innovation. In model 1 the independent variables described in the previous section are estimated one by one, while in models 2, 3, 4 we interact the industry-university R&D collaboration variable --which is of primary interest in our analysis-- with the variables of crisis, export activity and education dummies as follows: *R&D*Crisis* and *R&D*(1-Crisis)* for model 2, where Crisis takes the value of 1 for the year 2013, i.e. as the crisis deepens,

[5] If this firm is considered as an outlier and is omitted from the descriptive calculations then the average size is 116 (in 2013) and 134 (in 2011).

and the value of 0 for the 2011, i.e. at the beginning of the crisis. *R&D*Exporting* and *R&D*(1-Exporting)* for model 3, where Exporting takes the value of 1 if the firm is an exporter, and the value of 0 if it does not operate abroad. *R&D*Education* and *R&D*(1-Education)* for model 4, where Education is a dummy variable equal to 1 if the firm's percentage of high educated employees is above the 75th percentile of the distribution on the education variable and 0 otherwise. In this way, the regressions corresponding to the last 3 models enable us to explore the potential role of industry-university R&D collaboration as a mechanism through which firms in turbulent economic conditions as well as with different levels of knowledge stock could increase the likelihood for their entrepreneurial attempts to become innovative.

"Insert Table 5 about here"

The estimates in our baseline model (i.e. model 1) show that the probability of manufacturing firms in Greece to innovate is strongly and positively affected by industry-university R&D collaborations. This finding is in the same vein as other empirical and theoretical studies, which also suggest a positive relation between industry-science relations and innovation performance through the use of scientific knowledge (see Baum et al., 2000; Belussi et al., 2010; W. M. Cohen, Nelson, & Walsh, 2002; Feller, 1990; George, Zahra, & Wood, 2002; K. N. Kang & Park, 2012; Kline & Rosenberg, 1986; Mansfield, 1995; Mowery, 1990; Rosenberg & Nelson, 1994). This important finding can be explained on the notion of increasing knowledge returns created industry-university collaborations, which in turn may be successfully transformed in innovation output (e.g. Agrawal & Henderson, 2002; Agrawal, 2006; Henard & McFadyen, 2006; Monjon & Waelbroeck, 2003; Tether, 2002). The empirical results also reveal an inverted U-shape relationship between university R&D collaborations and innovation our study strengthening existing evidence that the relationship between knowledge flows- measured in terms of patents and external search- effort is not linear (Katila & Ahuja, 2002; Laursen & Salter, 2006; Wu & Shanley, 2009).

On the other hand, our results do not comply with previous findings that knowledge stocks positively impact innovation output (Wu & Shanley, 2009). Variables that stand for knowledge stocks -exporting, age, education- do not contribute to the innovation output. It seems that crisis erodes the effectiveness of

knowledge stocks on the innovation output. As it has been already pointed in the case of turbulent knowledge environments (Barnett & Sorenson, 2002) in abrupt times too, reconfiguring firm's knowledge base is necessary. Previous studies have also explained negative innovation effects based on path-dependency (Thrane, Blaabjerg, & Møller, 2010), core rigidities (Leonard, 1992) or search myopia (Levinthal & March, 1993) Thus, inherent characteristics of knowledge flows- that can be adjusted instantaneously (Dierickx & Cool, 1989)- are more prominent.

Indeed, our results indicate that the economic crisis deepening has a clear negative impact on the probability of firms to innovate. This finding is in accordance with Paunov, (2012) who provide empirical evidence that the recent global crisis caused significant innovation project discontinuations due to greater financial constraints. Another noticeable finding refers to the significant positive relationship that is found between innovation and differentiation strategy. A possible explanation is that during economic downturn firms that attempt to seek new business lines to acquire market share or open new markets seem to successfully cope with these difficult conditions through risk taking and experimentation. Thus, firms in such conditions characterized by market contractions and a collapse of internal demand (which is something that actually happened during the economic crisis in Greece) can establish their power and nullify their competitors' strength by identifying a new segment and serving new customers who have a different value system (Porter, 1985).

Furthermore, training of employees is found to facilitate product innovation in times of crisis. This finding can be explained by the fact that training facilitates employees' exposure to variety of knowledge and openness to innovative ideas (Beatty & Schneier, 1997; Brockbank, 1999; Jaw & Liu, 2003). The size of firms appears to matter in a positive and significant way for their innovation. Hence, firm size seems to affect the endowment of important inputs to the innovation process (Cassiman & Veugelers, 2006). With respect to the other independent variables examined, that is low cost strategy, competition intensity and liquidity constraints do not seem to either hamper or facilitate the innovativeness of the major entrepreneurial players in the Greek productive system in times of crisis.

Having identified a direct negative relationship between crisis deepening and innovation performance, model 2 attempts to identify if the effects of industry-university R&D collaborations on innovativeness have changed in the two waves of

the Greek economic crisis. Our findings reveal that R&D collaborations between private sector and universities drive innovation of firms as the crisis deepens, while this is not the case just after the crisis outbreak. This interesting result may imply that crisis facilitates the transition of the business productive system from a corporate model of knowledge production to a new distributed, inter-organisational, innovation model where joint networks and collaborations between universities and firms can more effectively combine resources, exploit increasing knowledge returns, reduce cost of failure of R&D projects and create value. Or simply it could be the effect of resources' constraints that most firms faced as the crisis was deepening.

In model 3 our objective is to verify whether there is a differential effect of industry-university collaboration on the innovation probabilities of exporting and non-exporting firms. This exercise is based on the consideration that exporting firms are expected to exhibit higher levels of knowledge stock since according to the self-selection argument exporters outperform in terms of productive capacity. The self-selection theory has been found more pertinent in empirical reviews (Wagner, 2007), while the results were mixed for learning-by-exporting theory. Hence, excess knowledge stocks enable exporting firms to build cross-border channels and networks compared to non-exporting firms. Interestingly, our findings suggest that non-exporting firms would benefit the most in the likelihood to innovate from the development of synergies in R&D projects with universities. Thus, our results suggest that non-exporting firms with low knowledge stock could invest to the generation of knowledge flows by collaborating in R&D with universities in order to improve their innovative performance.

In model 4 we explore whether the innovation of firms with different quality of human capital is affected in the same way by R&D collaborations with universities. Through education, people develop a number of characteristics such as intelligence, abstract thinking, curiosity, and a strong interest to find general solutions to problems which are usually associated with high creativity and high probability to perceive innovative business ideas (Koellinger, 2008). Education is also considered a condition for an individual to acquire the knowledge required for identifying specific entrepreneurial opportunities in response to a technological change (Shane, 2000). Our results show that firms with employees of lower educational level, i.e. with lower levels of knowledge stock, benefit more in terms of innovation when knowledge

flows take place through the use of external collaborations with universities, compared to firms with a high knowledge stock as proxied by the high educational level of their employees. Our findings suggest that personnel with high educational level may induce organizational rigidity that may inhibit the embeddedness of new knowledge from R&D collaboration with the universities in abrupt times. Overall, our findings suggest that in times of crisis, knowledge flows via the channel of firm-university R&D collaborations may drive effectively the innovation output process especially for firms characterized by low levels of knowledge stocks. In other words, knowledge flows act as a bridge for innovation when low levels of knowledge stocks are observed. Flows act as a replenishment mechanism when the stocks are low, allowing for higher impact on the innovation output when the knowledge stocks are high, flows fail to successfully drive innovation. This means that collaborating with universities in some R&D projects may actually compensate for skill shortages that hamper innovative performance. On the contrary high stocks create a lock in effect deterring firms from exploiting innovation opportunities that emerge from knowledge flows. A possible explanation of this finding could be that the accumulation of knowledge stocks may lead to organizational inertia within a firm operating in turn as a barrier to external learning (Adams, Day, & Dougherty, 1998; Wastyn & Hussinger, 2011).

5. Conclusions and Policy Implications

Given that the recent Greek crisis and the following recessionary economic cycle revealed the long-term roots of many exogenous and endogenous structural and strategic problems of the Greek economy, the need for restructuring the productive and business system towards a growth trajectory closely associated with technology upgrading and industrial improvement is more eminent than ever. The growth element in the economic policy was and is still missing; in particular, there is a lack of an "activating knowledge" systemic dimension. In a way, this empirical study attempts to contribute to the relevant policy discussion on how knowledge flows and knowledge stocks could interact effectively with each other in order to facilitate innovative performance of the business productive system in turbulent economic conditions. In specific, the primary purpose of this paper is to explore the role that collaboration with universities may play on innovativeness of manufacturing firms in

times of crisis. In doing so, we make use of a unique survey of field research data collected from 1500 Greek firms in the crisis years 2011 and 2013.

Using panel probit regressions we find that industry-university R&D collaborations is a contributor, carrier and facilitator of firm innovation in times of crisis. Moreover, when firms develop training programmes for their employees, pursue differentiation strategies and become larger, their innovative chances significantly improve. On the contrary, we show that the economic crisis deepening can reduce the probability of firms to be engaged in innovative attempts. When we consider whether the linkage between firm-university collaboration and innovativeness has evolved over the crisis period we find that R&D collaborations of firms with universities have an important role to play in shaping the innovating performance of firms in the midst of the crisis (second crisis wave) rather than immediately after the crisis outbreak (first crisis wave).

Our findings also suggest that firms with lower knowledge stocks, benefit more from knowledge flows in terms of product innovation process. In particular, we find that the beneficial innovative effects of external industry-university collaborations are more pronounced for non-exporting firms as well as for firms with employees of lower educational level. Thus, we empirically confirm our basic hypothesis that interactions of knowledge flows with knowledge stocks increase in a significant way innovation probability when the knowledge stocks are confined. In other words, knowledge flows can act as a bridge for innovation especially for firms characterized by low levels of knowledge stocks. This is particularly important for the portion of Greek manufacturing firms that seems to lag and do not participate in an exporting path. Such relationships with Universities can help these firms in augmenting their innovative performance, thus making them also contributors to an extrovert growth pattern of the Greek economy.

From a policy perspective, our results underline the need for the knowledge generation/diffusion system to be a priority in the economic policy-mix in order to create value and facilitate the recovery of the Greek economy in sustainable and competitive patterns. The adopted policy of harsh and long-lasting austerity measures with an exclusive focus on “cost-competitiveness” and general market-based structural reforms has led to a considerable progress in terms of fiscal management.

But, the cost for the Greek economy and society appears to be unacceptably excessively high in terms of loss of productive capacity, collapse of investment activity, unemployment, incomes reductions, inequality rise, tax burden on certain segments of society etc. Nevertheless, the adopted policy did not succeed in transforming the pattern of entrepreneurial activity and production, which has not been improved in qualitative terms and it is not at all evident that it will improve soon in terms of "structural" competitiveness.

Implementation of "activating knowledge" and "innovating out of crisis" growth strategy in the Greek context could be of crucial importance, as certain necessary institutions and the related capabilities are weak or missing. In particular, Greece was historically quick in perceiving the importance of technological and institutional innovations and undertaking relevant initiatives, but very slow in implementing them. Therefore, drafting the policy framework and providing the necessary incentives in general is not sufficient. In addition, the focus should shift from exclusive focus on general structural reforms to rely much more on identifying barriers and opportunities, missing links and capabilities across certain "extended value chains and related productive and business systems". In this respect, a process of engaging actors active in each of these value chains – and global value chains is possible - and allowing space for new actors to emerge should be activated.

A system of interrelated policies with concrete measures and a realistic roadmap backed by the co-ordinated mobilisation of existing and would be actors and resources should be in place for the successful implementation of the proposed strategy. More precisely, such a strategy should address five interwoven issues in a "what and how to" manner for the development of effective channels for university-industry knowledge transfer: i) enhancing joint research projects, joint pantenting and exchange of information on R&D results between universities and industry ii) creating a mobility system of scientists, academia, research personnel and managers between public knowledge institutes and industry, iii) investing and upgrading human resources through joint training programmes between universities and industry iv) organizing university-based science parks and business incubators, v) sharing of university laboratories and R&D departments of businesses.

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Table 1. Summary statistics for continuous variables

	Obs	Mean	Std. Dev.	Min	Max
Education (2011)	461	25%	21%	0	100%
Education (2013)	472	29,1%	24%	0	100%
Age (2013)	486	25	15	6	108
Size (2011)	524	165 [53]*	798	1	16524
Size (2013)	524	141 [50]*	653	1	13249

Notes: * Median value in squared brackets

Table 2. Summary statistics for categorical variables taking values in a Likert scale

	Obs	Mean	Std. Dev.	Min	Max
University_Firm R&D collaborations (2011)	518	1.87	1.15	1	5
University_Firm R&D collaborations (2013)	520	2.1	1.2	1	5
Liquidity constraints_Banks (2011)	520	2.85	1.46	1	5
Liquidity constraints_Banks (2013)	519	3.71	1.39	1	5
Liquidity constraints_Supply Chain (2011)	520	3.31	1.31	1	5
Liquidity constraints_Supply Chain (2013)	522	3.99	1.11	1	5
Price Based competition (2011)	517	2.73	1.26	1	5
Price Based competition (2013)	522	2.94	1.27	1	5

Table 3. Frequencies for binary variables

	Obs	Yes
Product innovation (2011)	520	59.8%
Product innovation (2013)	520	49.0%
Exporting (2011)	524	71%
Exporting (2013)	524	74%
Low cost strategy (2011)	520	50.6%
Low cost strategy (2013)	518	52.1%
Differentiation Strategy (2011)	514	38.3%
Differentiation Strategy (2013)	514	37.7%
Training (2011)	524	73.9%
Training (2013)	523	72.9%

Table 4. Correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
University-Firm R&D collaborations (1)	1.000										
Exporting (2)	0.054	1.000									
Education (3)	0.204	0.024	1.000								
Low cost strategy (4)	-0.035	-0.010	-0.077	1.000							
Differentiation Strategy (5)	0.097	0.044	0.099	-0.131	1.000						
Liquidity constraints_Banks (6)	0.033	-0.024	-0.036	0.030	-0.070	1.000					
Liquidity constraints_Supply Chain (7)	0.066	-0.093	-0.070	0.042	-0.087	0.567	1.000				
Price Based competition (8)	0.056	-0.012	-0.093	-0.028	-0.005	0.177	0.219	1.000			
Training (9)	0.172	0.123	0.202	0.041	0.001	-0.030	-0.071	-0.124	1.000		
Age (10)	0.056	0.133	0.007	0.019	-0.035	-0.007	-0.030	-0.024	0.107	1.000	
Size (11)	0.075	0.245	0.009	0.062	-0.053	-0.105	-0.187	-0.152	0.339	0.244	1.000

Table 5. Determinants of product innovation: Panel probit regressions for 524 manufacturing firms in the crisis years 2011 and 2013

Dependent Variable Product Innovation	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
R&D collaboration*Crisis Deepening		**0.135***			
		(0.073)			
R&D collaboration*(1-Crisis Deepening)		0.078			
		(0.076)			
R&D collaboration*Exporting			0.072		
			(0.065)		
R&D collaboration*(1-Exporting)			**0.197***		
			(0.116)		
R&D collaboration*Education				0.033	
				(0.067)	
R&D collaboration*(1-Education)				**0.14****	
				(0.064)	
R&D collaboration*young					0.03
					(0.077)
R&D collaboration*(1-young)					**0.126****
					(0.062)
University-Firm R&D collaborations	**0.531****				
	(0.261)				
University_Firm R&D collaborations_square	**-0.082***				
	(0.048)				
Crisis deepening dummy	**-0.468*****		**-0.412*****	**-0.451*****	**-0.447*****
	(0.124)		**(0.122)**	**(0.122)**	**(0.122)**
Exporting	0.285	0.218		0.282	0.275
	(0.175)	(0.168)		(0.172)	(0.172)
Education	-0.115	-0.287	-0.13		-0.139
	(0.328)	(0.313)	(0.325)		(0.322)
Age	0.049	0.003	0.04	0.04	
	(0.11)	(0.106)	(0.11)	(0.108)	
Low cost strategy	0.015	0.03	0.033	0.018	0.042
	(0.142)	(0.138)	(0.142)	(0.14)	(0.14)
Differentiation Strategy	**0.506*****	**0.481*****	**0.518*****	**0.502*****	**0.502*****
	(0.141)	**(0.137)**	**(0.14)**	**(0.139)**	**(0.139)**
Liquidity constraints_Banks	-0.029	-0.07	-0.036	-0.033	-0.034
	(0.055)	(0.052)	(0.055)	(0.054)	(0.054)
Liquidity constraints_Supply Chain	0.065	0.02	0.058	0.06	0.065
	(0.066)	(0.063)	(0.065)	(0.064)	(0.065)
Price Based competition	0.086	0.079	0.09	0.08	**0.09***
	(0.055)	(0.053)	(0.055)	(0.054)	**(0.055)**
Training	**0.32***	**0.341****	**0.366****	**0.378****	**0.363****
	(0.168)	**(0.161)**	**(0.165)**	**(0.162)**	**(0.164)**
Size	**0.245*****	**0.264*****	**0.276*****	**0.244*****	**0.275*****
	(0.073)	**(0.071)**	**(0.072)**	**(0.071)**	**(0.072)**

Notes: *Significant at 10% level. **Significant at 5% level. ***Significant at 1% level. Standard errors are reported in parentheses. Our estimates include sector dummies.