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The effect of Open Innovation activities during unstable economic conditions on subsequent product innovation performance

An analysis of German SMEs

Master Thesis

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Abstract

During the past decades, the business environment experienced vast changes and unstable economic conditions. The recent economic crisis had a pervasive influence on companies' viability and inhibited them in their innovation efforts. As a matter of fact, SMEs that typically possess fewer resources are even more constrained and affected during recessions. Much literature highlighted the strategic importance of Open Innovation practices for innovation performance. Specifically, technological co-operation is assumed to be one of the most effective Open Innovation activity that brings in external resources and thus influences product innovation performance. Nonetheless, even though some literature examined what types of companies are able to maintain or increase innovative efforts during recessions, few studies investigated in how far economic recessions change the willingness of companies to open up their innovation practices and the effect of R&D co-operation on subsequent product innovation performance. This research study investigates if open innovation activities are a possible strategy for SMEs to weather economic recessions and positively impact subsequent product innovation performance. Consequently, is gradually opening up innovation activities and participating in R&D co-operation during crisis beneficial? Having analyzed data of German SMEs, the study confirms that a higher degree of openness, compared to a closed innovation system during crisis positively affects radical and incremental innovation performance. Furthermore, R&D co-operation is more likely to affect only incremental performance. However, only vertical co-operation is found to be significant, whereas engaging with multiple different co-operation partners even deteriorates innovation performance.

Keywords: Open Innovation, Economic crisis, R&D co-operation, Product innovation performance, German SMEs

List of abbreviation

CIS – Community Innovation Service

DV – Dependent variable

IV- Independent variable

OI - Open Innovation

LR – Logit Regression

R&D - Research and development

SME - Mirco, small- and medium enterprise

VIF - Variance Inflation Factor

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1. Introduction

It is a prevalent vice that ever-changing economic conditions and fast rates of technological changes force companies to constantly bring forward new innovations (Brown & Eisenhardt, 1998; OECD, 2009). As a matter of fact, external economic conditions can impact the way how companies engage in the market. Specifically, the last economic crisis during the first decade of the 21st century had a pervasive influence on the economic viability of companies world-wide, also impacting their innovative efforts (European Commission, 2009). Ultimately, several companies cut their investments in innovation activities, which negatively affected their innovative output and consequently their overall performance (EC, 2009; Filippetti & Archibugi, 2011). In some countries, such as Germany companies persisted the recent crisis better than others due to their resilient economic fundamentals and established innovation systems. Even though these countries were able to recover to their pre-crisis level during the last years, they also experienced stagnating growth, weak investment activities and declined product innovations during the crisis years (KfW, 2015; Zimmermann, 2015; Appendix A).

Assessing the right innovation strategy is often a challenging task. Investing in internal research and development (R&D) to foster intra-companywide expertise and know-how has long been the leading strategy for companies to originate innovations. However, various reasons, as for instance a lack of financial resources, expertise and knowledge encouraged many companies to follow the trend towards Open Innovation (OI) (Calantone & Stanko, 2007). Therefore, many companies opened up their innovation practices to external partners as idea and knowledge instigator and for active participation in R&D co-operations (Chesbrough, 2003; Christensen et al., 2005). Following an OI strategy might become even more important for companies during economic recessions, as it can be a mean to overcome fundamental challenges of an economic crisis. Furthermore, this strategic decision somewhat

depends on companies' specific characteristics. The challenging economic conditions left their mark particularly on micro, small- and medium sized enterprises (SMEs[1]) (KfW, 2015). As SMEs are usually more constrained in their innovation activities and thus more vulnerable during economic recessions, open innovation activities for knowledge input and active co-operation might be a suitable alternative to secure subsequent innovation performance, as it can provide them with necessary resources which they are lacking (Schumpeter, 1934; Acs & Audretsch, 1987; Ozar et al., 2008;).

Following the well-known proverb "Necessity is the mother of invention" (The Oxford Dictionary, 2009), crises provide the chance to explore new opportunities to revitalize the economy by developing new innovations (Archibugi, Filippetti & Frenz, 2013). While adapting an opportunity- and risk seeking behavior, some companies might apprehend that engaging in innovation activities during crises can have a positive effect in the long-run. As "innovation will be one of the keys to emerging from the current crisis, but it risks being hit hard by the downturn" (OECD, 2009b, p.5) it seems necessary for companies to ensure active engagement in innovation activities even during unstable economic conditions. Therefore, it might be interesting to investigate if a high degree of openness for new knowledge input and exchange, as well as participating in R&D co-operations is a mean to proceed with economic recessions and secure subsequent innovation performance. Naturally, the question evolves what the effects of a high degree of openness regarding innovation activities, and active participation in R&D co-operation during economic crises are on subsequent product innovation performance of German SMEs. Specifically, to which degree of novelty does it lead? Hence, is a high degree of openness during economic crises reasonable? And does it make sense to participate in R&D co-operations? Within the empirical analysis, 1054 German

[1] Mirco, small and medium – sized enterprises (SMEs) are made up of enterprises that employ fewer than 250 persons and have an annual turnover not exceeding EUR 50 million. They are further distinguished into micro- (<10 employees), small- (<50 employees and medium-sized enterprises (<250 employees) (European Commission, 2003).

SMEs are examined, operating in manufacturing and service industries. Logit regression analyses are utilized to measure the impact of innovation activities during crises on the innovative performance of SME and comparing it to the pre-crisis period, controlling for unobserved and observed factors. For the purpose of this study, two distinct time periods are considered, namely the pre-crisis years from 2006-2008 and the during crisis years from 2008-2010, in order to capture the different effects of innovation co-operation on innovation performance.

1.1. Relevance and research gap

Much attention has been given to innovation research, particularly focusing on the growing importance of Open Innovation on companies' innovation performance (Gaynor, 2002; Atuahene-Gima, 2005; Cheng & Huizingh, 2014). Nonetheless, as more and more research is done, the more complex but also inconsistent its insights and findings become (Li and Atuahene-Gima, 2001; Rosenbusch, Brinckmann & Bausch 2011). While many scholars accentuate the advantages of OI practices on innovation performance (e.g. Van de Vrande, de Jong, Vanhaverbeke & Rochemont, 2009; Remneland-Wikhamn, Ljungberg, Bergquist & Kuschel, 2011), others revealed potential drawbacks of utilizing too many OI practices (e.g. Laursen & Salter, 2006; Berchicci, 2013; Hottenrott & Lopes-Bento, 2016). Furthermore, only very few studies have investigated companies operating under unstable economic conditions. Surprisingly, within this stream of research, most has been done on the innovation investment decisions of companies during crisis and specific company characteristics, lacking insights on particular innovation strategies companies can implement during crisis for securing subsequent innovation performance (Laperche Lefebvre & Langlet, 2011; Paunov, 2012; Archibugi et al., 2013).

Thus, to the best of my knowledge this study is the first that contributes to prior research by investigating the importance of the degree of openness and active participation in formal R&D co-operation with different types of partners when facing economic recessions. It distinctly focuses on German SMEs, since previous research mainly concentrated on large companies operating in high-tech manufacturing industries, neglecting the dominance of SMEs in the German market economy (KfW, 2015). An examination of German SMEs can give rise to answering why some countries were better able to recover from the recent financial crisis. The study aims to give general insights and suggestions and is not only of relevance to academic debate, but is also interesting for managers of SMEs as well as policy makers. Taking this as point of departure, the following research question is defined:

To what extent does opening up innovation practices and actively participating in R&D co-operation during economic crises benefit subsequent innovative performance of German SMEs?

1.2. Thesis outline

The remainder of this paper is structured in the following way: First, literature on Open Innovation and the effect of R&D co-operation on innovation performance within the context of the recent economic crisis is reviewed. Second, hypotheses are developed to answer the research question. Thereafter, the research methodology and data are presented, followed by an empirical analysis. Finally, the paper discusses the main results and examines the implications of the findings and gives future research recommendations.

2. Literature review

2.1. The concept of Open Innovation – from closed to open system

Within current dynamic environments, innovations are key drivers for economic stability and the success of company performance. Generally, innovation is a multi-faceted concept, which is best described as "The [generation and] transformation of an idea into the [production and] launching of a new or improved product, a new or improved industrial or commercial process, or a new method in which to serve society" (OECD, 1994, p.4). Companies are regarded as major engines for different types of innovation, such as technological innovations (e.g. process- and product innovations) and non-technological innovations (e.g. marketing- and organizational innovations) (Damanpour & Evan, 1984; Trott, 1998). Product innovations that are new to the company are termed 'incremental innovation'. If the innovation is new to the markets, and therefore considered as riskier, it is called 'radical innovation' (Athuhene-Gima, 2005). Obviously, innovations are of strategic importance for companies but are also fundamental for the economy (Drucker, 1998). In order to create new innovations, knowledge-capital is needed. It is a set of competencies and knowledge that reside within and outside company boundaries. Companies can acquire or produce knowledge-capital alone or together through co-operations with partners and networks (Laperche, 2008). This is in line with a more recent view of innovation that has received particular attention in the literature, and which focuses on the innovative implications of external sources. The distributed innovation practice, better known as Open Innovation, allows managing knowledge flows across company boundaries (Chesbrough & Bogers, 2014). Considering the obtainment of external resources for developing new innovations has become an integral part for many companies and their business strategies. Consequently, altering their predominant focus from mainly leveraging internal resources to external resources (Chesbrough, 2003; Chesbrough, 2006). Generally, openness can be considered as a continuum between closed and open

innovation activities. For the purpose of this research, it is defined as closed, if a company develops its innovation merely in-house, and open, if it gradually opens up its innovation practices by active informal idea input, joint product development or even taking over innovations developed by other companies. Besides, different forms of partner participation (Pisano & Verganti, 2008), the content of collaboration efforts (Huizingh, 2011), as well as the extent of partner breadth and depth (Laursen & Salter, 2006) have been also used to define degrees of openness. Commonly, the OI practice encompasses two different flows of knowledge, namely inside-out (outbound open innovation) and out-side in (inbound open innovation) flows (Chesbrough, Vanhaverbeke & West, 2006; Lichtenthaler & Ernst, 2006). Even though inside-out OI is becoming a common practice among companies the vast majority tends to make use of outside-in OI practices more frequently. To put it another way, this approach helps companies to gain competitive advantage by strengthening existing capabilities while exploiting new opportunities. For the purpose of this research, further analysis will concentrate on the primary knowledge inflow activities and their concomitant effects from the perspective of the focal company and focuses principally on innovation co-operation (Laursen & Salter, 2014) as for instance R&D co-operation with competitors, suppliers, customers, or research institutions, to produce products and services.

2.2. Open Innovation in SMEs

The performance effects of Open Innovation practices are contingent on distinct company-characteristics and the respective business environment companies operate in. Lichtenthaler (2005) has shown that companies in dynamic environments, characterized by technology turbulences, high transaction rates and intensified competition, benefit from OI activities.

Apparently, independent from their size, innovation plays an important role for companies and a vast majority of companies incorporate OI practices into their business strategies. Still,

much research investigated the effect of company size on innovation activities and stressed its importance on innovation performance (Acs & Audretsch, 1990). Due to various reasons, there are fundamental differences between Open Innovation practices in large companies and SMEs respectively. Generally, they differ in terms of Open Innovation practices intensity, selection of external partner relationships and their need for resources.

It has long been proven that innovation efforts require substantial resources. According to the European Commission (2013), SMEs represent 99% of all companies within the European Union. Even though research has shown that SMEs are likely to have higher R&D productivity than large companies (Audretsch & Vivarelli, 1996), many studies stressed the relative advantage of large companies in their innovation practices because of their possibility to draw from a considerable source of diverse resources. SMEs suffer regarding their innovativeness, since they lack resources and capabilities that are crucial for transforming inventions into new products and processes (Van de Ven, 1986). On the contrary, being small in size can have considerable advantages such as flexible structures and informal strategies (Narayanan, 2001). With regards to OI practices, only few studies have examined OI in SMEs (Van de Vrande et al., 2006; Lee et al. 2010; Brunswicker & Vanhaverbeke, 2011). Nonetheless, they stressed the underlying drivers that motivate SMEs to pursue OI activities and pointed out potential barriers of OI adoption. The fact that many SMEs do not possess enough resources and sufficient capacity to manage the entire innovation process emboldens them to engage in co-operation efforts with others outside their company boundaries (Edwards, Delbridge & Munday, 2005). Even though a high level of risk and potential cost reduction are further drivers for SMEs to consider external resources (Hagedoorn, 1993; Cooper, Edgett & Kleinschmidt, 2003; Trott & Hartmann, 2009), it needs to be carefully considered, since cross-company co-operation can also imply high transaction costs in form of coordination and intellectual property protection efforts and can lead to diminishing returns

(Lichtenthaler, 2005; Rosenbusch et al., 2011; Hottenrott & Lopes-Bento, 2016). As aforementioned, SMEs are prone to take advantage of crisis situations, since they can easily adapt due to their smaller size and flexible structures. However, this size advantage can also be a potential constraint. Due to their liability of smallness, most SMEs depend on external resources regarding their innovation efforts and performance, especially during economic recessions where resource become even scarcer (Parida, Westerberg & Frishammar, 2012). They tend to lack resources for developing new innovations internally, thus making OI an attractive innovation practice (Nooteboom, 1994; Porter, 1998; Van de Vrande et al., 2006).

2.3. Innovation during economic recessions

The performance of companies is certainly influenced by external factors, as for instance the functioning of capital markets, market rivalry, governmental policies, and unstable economic environments. The recent financial crisis of 2008-2009 that led to an unprecedented global economic recession affected many companies. The roots of the recent economic crisis are diverse. However, irrespective of the cause, the crisis had a pervasive negative effect on the global economy (OECD, 2009). Even though, the crisis impaired the financial stability of most companies and thus their overall performance, little is known about its effect on companies' innovation capacities (OECD, 2009b). Generally, decreasing innovation performance can be one of the major causes for declined overall performance in the long-term, since it is confirmed that innovation is one of the major driver of growth and economic prosperity (Grossman & Helpman, 1991; Hausman & Johnston, 2014).

2.4. Pro-cyclical versus counter-cyclical behavior

As a reaction to the crisis, companies can either follow a pro-cyclical behavior, by cutting costs and reducing investments as well as innovation spending or to follow counter-cyclical

behavior by actively remaining or even increasing innovation activity (Schumpeter, 1939; Aghion & Saint-Paul, 1998; Filippetti & Archibugi, 2011). Evidence from the previous crisis shows mixed support for both pro-cyclical and counter-cyclical patterns. A study conducted by McKinsey claims that the majority of companies plan to spend less on R&D activities during 2009 (McKinsey&Company, 2009), whereas other research found out that most companies declared to have remained their innovation investments unchanged during the recent crisis (Archibugi & Filippetti, 2011).

However, as a matter of fact the economic recession has contributed to the decrease in innovation performance for most countries, as many companies behaved pro-cyclical and ceased to invest in innovation activities, specifically in R&D investments (OECD, 2009b; McKinsey&Company, 2009; Archibugi & Fillippeti, 2011). Francois and Lloyed-Ellis (2003), claim that innovation investments tend to be pro-cyclical, making it even more challenging for companies to operate during economic recessions. Furthermore, as Hall and Lerner (2009) point out, there are numerous reasons, as for instance the high involvement of risk and uncertainty of innovation investments that make external financing more difficult, since banks and investors have become more risk averse. Moreover, due to the shift towards a knowledge-based economy, investments in intangible assets have become as essential as investments in tangible assets, making companies becoming increasingly cautious of losing idiosyncratic knowledge and capabilities to others (Laperche et al., 2011). This in turn might make companies more reluctant to pursue OI activities, as they fear knowledge spillovers. This is true for large companies as well as SMEs. However, small companies are more probable to discontinue innovation efforts, since they cannot draw from a broad resource base and they additionally face more problems in accessing external financing due to their lack of proper collateral (Paunov, 2012). Since costs cannot be covered as easily as under economic prosperity, companies often postpone R&D investments or simply re-orient towards short-

term and low risk innovations which consequently affects the job market (Hausman & Johnston, 2014). Though, discontinuing investing in innovation- and knowledge projects can have severe impacts on a company's long-term innovation performance, because they might risk the possibility of losing track of previous innovation paths and impede involvements in company networks (Paunov, 2012).

On the other hand, the past has shown that economic recessions are also times of industrial renewal (OECD, 2009b). Some companies recognize that economic recessions can bear several opportunities, as the economy will recover at some point. This recovery will bring about a new economic cycle with structural changes. Evidently, some of the most known products and services, as for instance Microsoft and Apple emerged from economic recessions, since they introduced innovations to a market that desired new offerings (Rae-Dupree, 2008). According to the creative destruction theory of Schumpeter (1934), some companies, specifically SMEs, are able to take advantage of downturns, by even increasing their investments on R&D and innovation, irrespectively of the business cycle (Koberg, 1987; Hundley, Jacobson & Park, 1996). In addition to the creative destruction theory, prospect theory can also stimulate innovation activities during economic downturns as facing losses increases risk seeking behavior (Kahnemann & Tversky, 1979). Applying this theory to the increased losses companies face during economic decline, it can be assumed that smaller companies are prone to lose more during economic recessions. Therefore, it might be the case that they are more likely to engage in innovation activities by following an explorative or exploitative approach during economic crisis in order to survive (Levinthal & March, 1993; Lavie & Rosenkopf, 2006; Posen & Levinthal, 2012). Whereas exploration implies discovery and risk taking, exploitation rather denotes refinement and increased efficiency (March, 1991). Furthermore, due to certain characteristics, such as flexibility and their rather specialized focus, SMEs are better able to adapt their businesses according to new economic

conditions. This is in line with Antonioli et al. (2010), who found out that SMEs tend to be more innovative during economic crises than large firms. However, even though it seems that SMEs have some advantages in pursuing innovative activities during recessions, they still lack one of the most essential aspects for developing innovation, namely resources. Referring to the exploration and exploitation approach, both can be executed on internal- as well as external resources, whereby exploration is rather based on external resources (Rosenkopf & Nerkar, 2001). As "[…] investment in research and development (R&D) is essential for firms and nations to produce innovations and compete for the future" (Tellis, Eisingerich, Chandy & Prabhu, 2008, p.2), companies, especially SMEs, might benefit from open innovation activities and R&D co-operation efforts during crisis, as they can make up for their lack of own resources and relieve them of financial pressure as costs can be shared (Cincera et al. 2012).

So, despite the reduction in innovation investments during recessions (Cincera et al., 2012; OECD, 2009), smaller companies (Archibugi et al., 2013) as for instance SMEs that succeeded to be innovative, might have benefited from opening up their innovation activities and participation in R&D co-operation to cope with the recession.

3. Conceptual Framework and Hypotheses Development

3.1. The effect of economic crisis on product innovation performance

Certainly, the recent global financial and sovereign debt crisis have had severe effects, such as increased uncertainties regarding future developments, a reduction on the overall demand for products and weakened financial systems (OECD, 2012). This in turn impaired the short-term willingness of companies to invest in innovation, which ultimately affects innovation performance (OECD, 2009; Paunov, 2011). Furthermore, several companies even discontinued their ongoing innovation projects and thus affected the decisions to abandon risky projects (Paunov, 2011). Even though, some research found out that some companies were able to keep up their innovative efforts, overall innovation activities declined during crisis, leading to the following hypotheses:

H1a: *An economic crisis has a negative impact on the probability of subsequent radical innovation performance.*

H1b: *An economic crisis has a negative impact on the probability of subsequent incremental innovation performance.*

3.2. Degree of openness during crisis

According to Jaruzelski and Dehoff (2010) open innovation is one of the most essential capabilities for innovative companies, in prosperity but also during recessions. Generally, companies can choose among three different strategies on a continuum, ranging from closed, to semi-open, to open (Barge-Gil, 2010). In this research, the degree of openness refers to the general attitude of companies' towards OI activities with regards to the inclusion of external ideas and impulses for product development (Som, Jäger & Maloca 2014). It can be measured by assessing if a company develops its innovation merely in-house or if it opens up its practices to externalities for idea input or joint innovation development. Usually, as business environments are becoming more complex and uncertain, it is assumed that more and more

companies start opening up their innovation activities when developing innovations. Generally, the concept of open innovation advocates that companies can enhance their ability to innovate by gradually opening up innovation activities to take in new knowledge (Laursen & Salter, 2006). Nonetheless, it is assumed that companies should not neglect focusing on internal resources, but rather finding the right balance between the importance of external- and internal resources (Chesbrough, 2006). However, particularly during economic recessions, innovation practices become a crucial aspect. On the one hand, opening up innovation activities to external environments for new impulses marks up transaction costs and increases the risk of losing tacit knowledge and ideas to others (Laperche et al., 2011). Furthermore, too much focus on new knowledge can ultimately result in several underdeveloped ideas (March, 1991). On the other hand, SMEs tend to be even shorter on resources during recessions, which consequently impede their innovation efforts. Thus, SMEs that usually have a limited base of internal knowledge can significantly benefit from a high degree of openness that possibly brings in resources that are relevant as instigators for new innovations and foster learning and further development. Acquiring new resources during recessions can therefore give rise to improving products or even developing radical innovations. Opening up innovation practices can possibly support a reduction of irreversible costs of the innovation process (Tether, 2002; Nieto and Santamaría, 2010). Combining these arguments with the aforementioned concept of counter-cyclical behavior and prospect theory, the following hypotheses are developed:

H2a: *Opening up the innovation practices during economic crisis is positively related to subsequent radical innovation performance.*

H2b: *Opening up the innovation practices during economic crisis is positively related to subsequent incremental innovation performance.*

3.3. R&D co-operation and partner selection during crisis

Evidently, economic recessions that severely impact the business landscape, force companies to alter their current innovation strategies. Next to new idea- and knowledge input, particularly R&D activities are regarded as main driver of growth in industrialized economies. In fact, stagnation of R&D activities can have vehement ramifications on the subsequent stabilization of the economy (Aghion & Howitt, 1998). Even though R&D activities are crucial, a vast majority of companies start cutting their investments in R&D (OECD, 2009b). Therefore, changing towards an R&D co-operation strategy might be a suitable approach, as its main aim is pooling knowledge while sharing costs. In other words, R&D co-operation facilitates offsetting the limitation of internal resources (Laperche et al., 2011). Apparently, when engaging in R&D co-operation, the choice of a co-operation partner highly depends on the actual intention of a company, as distinctive co-operation partners provide access to different types of knowledge and can give rise to different collaboration constellations (Cassiman, Di Guardo & Valentini, 2009). Usually, co-operation can take place either vertically by engaging with suppliers or customers, horizontally (e.g. with competitors), or diagonally (e.g. by participating with universities or public research institutions) (von Hippel, 1988; Belderbos, Caree & Lorkshin, 2004).

3.3.1. Vertical R&D co-operation

Vertical co-operation partners are of substantial importance for companies, as they are an integer part of a company's supply chain. Prior research has identified mixed findings associated with vertical partner co-operation (Belderbos, Caree & Lorkshin, 2004; Nieto & Santamaria, 2007). With regards to R&D co-operation, customer can serve to advance the effectiveness of new product development processes in early stages, since they can help to ensure market acceptance and commercialization of new product innovations, which in turn reduces the risk involved in new product introductions (Campbell & Cooper, 1999; Nieto &

Santamaria, 2007). Even though it can be difficult to assess the tacit knowledge from customers, their insights can give rise to the development of improved products or even stimulate the creation of totally new products (Schweitzer & Gabriel, 2012). Specifically, during times of recessions, co-operating with customers for R&D purposes can ensure customer satisfaction and the development of the right products. Furthermore, customer R&D co-operation usually does not involve a high risk of losing tacit knowledge (Belderbos et al., 2004), which is also true for supplier co-operation. Co-operating with suppliers can come along with reduced costs and cycle time (Petersen, Handfield & Ragatz, 2003), as relationships with suppliers involve high level of trust. Moreover, due to complementary capabilities and materials, supplier R&D co-operation can facilitate the development of radical innovations (Song & Benedetto, 2008) and incremental innovations (Belderbos et al., 2004). As the demand for complementary assets and trust increases for SMEs during times of recessions, the following hypotheses are developed:

H3a: *Engaging with vertical R&D co-operation partners during economic crisis is positively related to subsequent radical innovation performance.*

H3b: *Engaging with vertical R&D co-operation partners during economic crisis is positively related to subsequent incremental innovation performance.*

3.3.2. Horizontal R&D co-operation

Generally, companies that are competing with each other act according to their diverging self-interests. However, when co-operating with competitors, companies base their interaction on a common goal (Cassiman et al., 2009). Usually competitor R&D co-operation can help to access markets, as joint development ensures the interoperability of products and allows them to share the risks and costs involved. Furthermore, coopetition can unite competitors and increase their market power, thus giving them a competitive advantage against other companies in the market (Ritala, 2012). These aspects might be especially important for

SMEs, due to their limited resource capacity and market share (Gnyawali & Park, 2009). However, the advantages of competitor R&D co-operation might turn into potential disadvantages during crisis times, as companies become afraid of knowledge spillovers that reveal confidential information, which in turn might impact prospective market leadership (Quintana-Garcia & Benavides-Velasco, 2004). Furthermore, it has been proven that coopetition becomes ineffective in highly competitive environments, such as recessions (Ritala, 2012). Thus, the trade-off between accessing complementary resources and the potential threat of losing tacit knowledge and the possibility of opportunistic behavior lead to the following hypotheses:

H4a: *Engaging with horizontal R&D co-operation partners during economic crisis is negatively related to subsequent radical innovation performance.*

H4b: *Engaging with horizontal R&D co-operation partners during economic crisis is negatively related to subsequent incremental innovation performance.*

3.3.3. Diagonal R&D co-operation

Co-operating with universities or public research institutions has become a usual habit for many companies, as it is a comparatively easy way to acquire knowledge due to their nature of "open science" (Un, Cuervo-Cazurra & Asakawa, 2010). Getting involved with scholars and students for the development of innovations can enhance learning and cultivate the internal knowledge base with latest knowledge (Lam, 2007; Malva & Caree, 2013). Prior research has shown that R&D co-operations with diagonal partners are especially beneficial for product innovations (Robin & Schubert, 2013) and are also likely to lead to radical innovations (Belderbos et al., 2004). Nevertheless, some research found out that universities favor to work in co-operation with larger companies, as they tend to have greater financial resources for R&D and sophisticated technological capabilities, allowing for better opportunities with regards to new research initiatives (Beise & Stahl, 1999). However, if

SMEs manage to create co-operation relationships with diagonal partners they certainly benefit from low risk involvement and the chance to enhance their scarce resource base, as it becomes even more important during economic recessions. Therefore, the arguments support the following hypotheses:

H5a: *Engaging with diagonal R&D co-operation partners during economic crisis is positively related to subsequent radical innovation performance.*

H5b: *Engaging with diagonal R&D co-operation partners during economic crisis is positively related to subsequent incremental innovation performance.*

3.3.4. R&D co-operation with multiple partners

Some companies decide to cooperate with a limited amount of different co-operation types, whereas others utilize a wide range. Engaging in multiple co-operations can possibly provoke problems and inefficiency (Laursen & Salter, 2006; Hottenrott & Lopes-Bento, 2016). In a similar vein, Laursen and Salter (2006, p.132) point out, that "the benefits to openness are subject to decreasing returns, indicating that there is a point where additional search becomes unproductive". Indeed, it is confirmed by some research that companies that innovate through co-operation with others generally engage with fewer partners (Barge-Gil, 2010). However, during economic crisis, benefits from co-operating with a wide variety of different partner types might be higher and can facilitate access to diverse knowledge that helps to develop relevant and new innovations. Thus it might be expected that engaging with a broader range of different external co-operation partners leads to more synergies and a broader intake of complementary knowledge that ultimately leads to improved innovation performance (Belderbos, Carree & Lorkshin, 2004; Nieto & Santamaria, 2007). It can be argued that in order to increase the chances of acquiring valuable resources and knowledge companies rather decide to engage with multiple co-operation partners, than with only specific ones as they become more distressed during economic crisis. On the other hand, as SMEs are limited due

to their liability of smallness, they might be unable to cope with a diverse set of co-operation types, as it also incorporates high costs. Yet, even though participating with a diverse set of co-operation types can bear several advantages, the risks of high transaction costs and the exposure of tacit knowledge to others, outweighs the opportunity of bringing in new knowledge and expertise during economic crisis. Outgoing spillover effects are prone to be higher than incoming spillover effects (Beck, Lopes-Bento & Schenker–Wicki, 2014). This reasoning leads to the formulation of the following hypotheses:

H6a) *Engaging with a wide variety of different co-operation types during economic crises is negatively related to subsequent radical innovation performance.*

H6b) *Engaging with a wide variety of different co-operation types during economic crises is negatively related to subsequent incremental innovation performance.*

4. Methodology

4.1. Context

The financial crisis that commenced during summer 2007 affected the real economy and transformed into a global financial crisis at the end of 2008. Thus, companies experienced the main effect of the crisis in 2009, which is in line with Hud and Hussinger (2015) who consider 2009 as the year of the beginning of the crisis for German companies. As aforementioned, as a reaction to the crisis many companies started to alter their innovation strategies. Therefore, the main purpose of this research is to first examine the effect of generally opening up innovation activities during crisis and more specifically investigating the effect of R&D co-operation during crisis on subsequent innovation performance and comparing this to pre-crisis behavior.

The research study builds on earlier research and enlarges this topic by investigating hypotheses with a specific focus on SMEs in Germany. The research follows an industry-wide investigation and will be analyzed by using secondary quantitative data.

4.2. Sample and procedure

The empirical analysis uses data from the Mannheim Innovation Panel (MIP), conducted by the Centre for European Economic Research (ZEW) in close cooperation with the Frauenhofer Institute for System and Innovation Research (ISI) and infas. The Innovation panel is send out on a yearly basis since 1993 as part of the Community Innovation Survey (CIS) of the European Commission. In line with the Oslo Manual, the survey is based on a stratified random sample of companies that are operating in all sectors of the German economy. Each survey wave covers a three-year observation period for innovation performance, which is in line with the recommendation of the Oslo manual. Thus, the panel

data structure makes it possible to investigate innovation activity of German companies over time.

For the purpose of this study, namely the investigation of the effect of OI innovation activities on innovation performance during unstable economic conditions, three different survey waves have been taken into consideration. In order to examine the difference between stable and unstable economic conditions, two separate models have been developed respectively resulting in a cross-sectional data structure (Bryman & Bell, 2007). In order to investigate the effect of OI activities on subsequent product innovation performance, a time lag between the independent (IV) and dependent variables (DV) have been taken into account, as innovations need time to be developed. Former studies have shown an average period of at least 2 to 3 years for R&D projects (Pakes & Schankerman, 1984; Lavie & Miller, 2008). Each survey wave comprises data of three preceding years. Therefore, the independent variables for the pre-crisis years are taken from the survey wave of 2009, which covers data to measure the degree of openness and R&D co-operation during 2006-2008. To measure the effect of these OI activities on innovation performance and account for the time it takes to actually develop innovations, the concomitant dependent variables are taken from the survey of the year 2011, which contains data on product innovation performance of the three-year period from 2008-2010. The during crisis period is covered by the survey waves from 2011 and 2013 respectively, measuring the IV over the time period of 2008-2010 and the DV over the time period of 2010-2012. This timeframe division finds additional support with regards to the macro economic indicator of real GDP growth in Germany (Appendix A). It is important to mention that for each model, pre- and during crisis, data from the two different survey waves have been merged along company IDs to secure that the IV and the DV belong to the same company.

In addition, the analysis focuses on companies in manufacturing and service industries. Furthermore, only companies that report to be engaged in product innovations are used for the analysis. Overall, after further elimination of missing values and filtering for company size, the final sample size results into N=1054 German SMEs.

4.3. Measures

4.3.1. Dependent variables

Previous research has shown that there are various options to measure innovation performance. Generally, it can be measured by either the input-side, as for instance R&D expenditures or the output-side, such as a proxy for innovation performance like patent citations and counts or new products (Hagedoorn & Cloodt, 2003). In line with Kim & Park (2010) the output-side approach is used for this study and measured on a binary scale. However, the dependent variable is further distinguished between radical and incremental product innovation. If a SME has indicated that it has introduced products that were "new to market", the variable *radical_inno* takes the value "1", and "0" if it not. If a product was introduced that was "new to the company", the variable *increm_inno* is given the value "1", and "0" if otherwise (Kaufmann & Tödtling, 2001; Tether, 2002).

4.3.2. Independent variables

The survey provides sufficient information to investigate the aforementioned hypotheses. The general tendency towards Open Innovation, namely the opening up of innovation practices for new product development is measured by binary variables. This method is recommended as it cannot be completely assured that the survey information has interval properties (Stevens, 1946). If a company is not involved in OI or carries out the development of product innovations internally the variable *deg_open_low*, indicates a low degree of openness, if = 1 (otherwise = 0) and is used as base category in the analysis. The other variables on the

continuum are *deg_open_medlow*, *deg_open_medhigh* and *deg_open_high,* and are measured if a company developed an innovation together with other companies, by adapting products developed by others or by letting other companies completely develop new innovations on their own, respectively.

The independent variables for testing the hypotheses on R&D co-operation[1] are measured on a dichotomous scale. Hence, for each of the specific R&D co-operation partners, namely vertical-, horizontal and diagonal, the value "1" is assigned if the company actively co-operated with that specific kind of partner, and "0" if the company did not co-operate. Within the survey, co-operation partners are further distinguished according to their location, national or international. Due to the focus of this study, new variables have been created for each of the three different co-operation types, by assigning the value "1" if the company participates with either a national or international co-operation partner. The final variables are co-operation with customer and supplier (*vertical_coop)*, co-operation with competitors (*horizontal_coop)* and co-operation with universities and public research institutions (*diagonal_coop)*.

The last variable concerns the simultaneous co-operation with multiple different types. The variable *co-type* has been constructed, which determines the number of different co-operation types that a company engages with. Due to the binary nature of the different co-operation type variables, the values were added so that each company was assigned a value from 0 to 6, with 6 being the highest possible number of different co-operation partners.

In order to examine the difference between the pre-crisis and during crisis period, the dichotomous variable *crisis* is implemented, which takes on the value "1" for all companies in the data set that belong to the during crisis period and a "0" for all companies within the pre-

[1] The mere contracting-out of R&D is excluded from this definition.

crisis period. Furthermore, the above mentioned explanatory variables will be interacted with the crisis dummy, in order to analyze the full effect.

4.3.3. Control variables

In order to reduce the effect of other factors that can have an influence, control variables are included in order to enhance the validity of the research analysis (Field, 2009; Pallant, 2011). The variable *ln_firmsize* is included in the model and measured by the amount of employees, since much research stressed the positive relation between firm size and innovation performance (Audretsch & Vivarelli, 1996). The logarithmic transformation was applied to transform the heavily skewed distribution of the firm size into a symmetric distribution (Hamilton, 2008, p. 142; Wooldridge, 2008; Appendix B). This variable is included as former studies have demonstrated that larger companies usually perform better (Stolwijk et al., 2012). In line with the NACE classification, all SMEs within this data set are classified into 4 industry groups. By including dummy variables, for the low (*tech_l*) and high technology sector (*tech_h*) as well as the knowledge intensive sector (*kis_h*) and less knowledge-intensive sector (*kis_l*) that is used as base category, differences between the different industries can be controlled for. The research controls for the origin of the company, namely former west- or east Germany (*east*) are measured on a binary scale, taking on the value "1" for east and "0" for west. Next, a distinction between the geographical target markets the company operates in is made. The variable *target_mkt* ranges from local to international and takes on the values from 0 to 3 respectively, taking on "0" as base level. Due to the purpose of the study it is important to control for R&D expenditures (*RD_exp*), as earlier research shows that companies which actively invest in R&D tend to perform better (Hung & Chou, 2013). *RD_exp* is measured by R&D expenditures divided by total turnover and truncated at 0.15 because of anonymization reasons. In the appendix, an overview and a thorough description of all variables that are used in this research can be found (Appendix C).

4.4. Analytical strategy

A logistic regression is applied to investigate whether the above mentioned independent variables show significant influence on the occurrence of radical and incremental innovations (Bowerman, O'Connel & Murphree, 2009; Field, 2009). Unlike a linear regression, this technique makes use of the maximum likelihood estimation, which helps to predict the likelihood of the occurrence of a specific outcome, and does not require a linear relation between the variables (Peng, Lee & Ingersoll, 2002). In the case of this research study, two models are developed to investigate and test the different independent variables on each of the two dependent variables. Thus, the analysis aims to predict if open innovation activities and R&D co-operation during crisis increase or decrease the probability of introducing radical- or incremental innovations to the market, and predicts the scope and direction of the influence of each of the different independent variables on the dependent variable. Within the two models, the set of independent variables will be the same. Moreover, by using a pooled approach, both time periods, pre- and during crisis, are included at once via interaction terms in each of the two models. This facilitates a direct comparison of the time periods and highlights the direct effect of the crisis. In general, the logistic regression estimate P(Y) is the probability of Y to occur given the values of X_1 to X_i (Field, 2009). Y_i is a binary Variable with the following coding:

$$Y_i = \begin{cases} 1 & \text{If company i launched an innovation} \\ 0 & \text{If company i did not launch an innovation} \end{cases}$$

Note that this variable Y_i is defined separately for both dependent variables (radical and incremental innovation). Let further denote $P(Y_i = 1)$ as the probability of company i launching an innovation (Wooldridge, 2008).

The estimated logistic regression equation then is defined by the following equation (Hilbe, 2016, p.49):

$$\log\left(\frac{P(Y_i = 1)}{1 - P(Y_i = 1)}\right) = \alpha + \beta_1 deg\_open\_medium\_low + \beta_2 deg\_open\_medium\_high + \beta_3 deg\_open\_high + \beta_4 co\_type + \beta_5 vertical\_coop + \beta_6 horizontal\_coop + \beta_7 diagonal\_coop + \beta_8 crisis + \beta_9 tech\_high + \beta_{10} tech\_low + \beta_{11} kis\_high + \beta_{12} ln\_firmsize + \beta_{13} RD\_exp + \beta_{14} target\_mkt + \beta_{15} east$$

This is done once for each of the two dependent variables. In a second step, the model is complemented with interaction terms of *crisis* and *deg_open*, *crisis* and *coop* as well as *crisis* and *co_type*. This results in the following Regression equation:

$$\log\left(\frac{P(Y_i = 1)}{1 - P(Y_i = 1)}\right) = \alpha + \beta_1 deg\_open\_medium\_low + \beta_2 deg\_open\_medium\_high + \beta_3 deg\_open\_high + \beta_4 co\_type + \beta_5 vertical\_coop + \beta_6 horizontal\_coop + \beta_7 diagonal\_coop + \beta_8 crisis + \beta_9 crisis * deg\_open\_medium\_low + \beta_{10} crisis * deg\_open\_medium\_high + \beta_{11} crisis * deg\_open\_high + \beta_{12} crisis * vertical\_coop + \beta_{13} crisis * horizontal\_coop + \beta_{14} crisis * diagonal\_coop + \beta_{15} crisis * co\_type + \beta_{16} tech\_high + \beta_{17} tech\_low + \beta_{18} kis\_high + \beta_{19} ln\_firmsize + \beta_{20} RD\_exp + \beta_{21} target\_mkt + \beta_{22} east$$

Furthermore, to ensure valid results different model fitness statistics, such as the log likelihood, the Homsomer-Lemeshow test, the Cox & Snell R^2 plus the Nagelkerke R^2 as well as the Omnibus test for model coefficients and the concomitant chi-square statistic, are compared (Pallant, 2011; Peng, Lee & Ingersoll, 2002).

5. Results

Within this chapter, the results of the two models that have been used to test the aforementioned hypotheses are described. First descriptive statistics give a profound overview of the data. Thereafter, the analysis is further divided into the preliminary and the main analysis.

5.1. Descriptive statistics

Descriptive statistics and frequencies of the relevant variables are presented in the following tables. The description is done separately for the crisis- and the pre-crisis period, where 357 (22.87%) observations belong to the pre-crisis period and 697 (66.13%) to the crisis period. Table 1 shows the frequencies of the two dependent variables for each of the two periods. According to table 1 both kinds of innovation are less frequent during the crisis period. The difference in the percentage of occurrence of both kinds of innovation differs about 20% between crisis and pre-crisis.

Table 1: Frequencies of radical and incremental innovations

			N	%
Radical Inno.	No crisis	no	178	49.86
		yes	179	50.14
	Crisis	no	474	68.01
		yes	223	31.99
	Overall	no	652	61.86
		yes	402	38.14
Incremental Inno.				
	No crisis	no	147	41.18
		yes	210	58.82
	Crisis	no	438	62.84
		yes	259	37.16
	Overall	no	585	55.50
		yes	469	44.50

Table 2 shows in an analogous manner the frequencies of vertical-, horizontal- as well as diagonal co-operation. This table is interesting, because it shows how frequent different types of co-operation do occur in crisis and pre-crisis periods. Table 2 displays that each kind of co-operation is more frequent during the pre-crisis period than during the crisis period. Note that horizontal co-operation is by far the least common co-operation.

Table 2: Frequencies of different co-operation types

			N	%
Vertical coop.	No crisis	no	263	73.67
		yes	94	26.33
	Crisis	no	567	81.35
		yes	130	18.65
	Overall	no	830	81.35
		yes	224	78.75
Horizontal coop.	No crisis	no	326	91.32
		yes	31	8.68
	Crisis	no	659	94.55
		yes	38	5.55
	Overall	no	985	93.45
		yes	69	6.55
Diagonal coop.	No crisis	no	248	69.47
		yes	109	30.53
	Crisis	no	520	74.61
		yes	117	25.39
	Overall	no	768	72.87
		yes	286	27.13

Table 3 presents the frequency distribution of the variable degree of openness. The result is ambiguous, because the level “low” is more frequent in the pre-crisis period while the level “high” does occur more often in the crisis period. However, the difference between the frequency of “low” is quite large, indicating that a crisis goes along with lower openness.

Table 3: Frequencies of degree of openness

	Openness	N	%
No crisis	Low	160	44.82
	Med. Low	149	41.74
	Med. High	37	10.36
	High	11	3.08
Crisis	Low	421	60.4
	Med. Low	192	27.55
	Med. High	54	7.75
	High	30	4.3
Overall	Low	581	55.12
	Med. Low	341	32.35
	Med. High	91	8.63
	High	41	3.89

Table 4 contains descriptive statistics of the variable that are used as numerical variables. For better readability, number of employees (*employ*) is included, although it is not used in regression analysis.

Table 4: Descriptives of numerical independent variables

variable	N	mean	sd	min	max
co_type	1054	0.61	1.08	0.00	6.00
employ	1054	55.58	63.67	0.76	341.78
ln_firmsize	1054	3.37	1.21	-0.27	5.83
RD_exp	1054	0.03	0.04	0.00	0.15
target_mkt	1054	1.94	1.12	0.00	3.00

Finally, table 5 presents the frequency of the economic sectors of the analyzed companies. The largest part of the sample are industrial companies.

Table 5: Frequency of industry sectors

Industry sectors	N	%
Research-intensive industry	320	30.36
Less research-intensive industry	400	37.95
Knowledge-intensive ind.	252	23.91
Less knowledge-intensive ind.	82	7.78

5.2. Preliminary results

Before continuing with the statistical regression analysis, the validity of the results has to be ensured. In order to investigate the relationship between the variables included in this study, Pearson's correlation coefficients are presented in the appendix (Appendix D). As the independent variables should not correlate with each other to prevent from biased and multicollinearity, it is important to notice that none of the correlation's absolute values are above 0.8. Usually, it is recommended to only use independent variables whose pairwise correlation does not exceed the absolute value of 0.8 (Kennedy, 2003, p. 209).

According to Tabachnick & Fidell (2011), the interpretation of correlation coefficients has certain limitations. A further method to identify potential correlation is the calculation of variance inflation factors (VIFs). These values help to assess how much an independent variable is not explained by others in the same model. In the case of the VIFs, values that are above 0.10 indicate high correlation (Field, 2009). Appendix E reports the values of the VIF for the set of independent variables. As the values are within the above specified limits, 1.08 and 7.73, it can be stated that there is no multicollinearity present in the analyses (Wooldridge, 2008, p. 99).

5.3. Economic results

The regression results are presented in table 6. For each model the overall LR (likelihood-ratio) test is reported as well as McFadden's Pseudo R^2. In each of the four models, the overall LR-Test shows a significant value ($p<0.01$) meaning that each of the models has a significant explanatory power for the dependent variable. The Pseudo R^2 takes on values between 0.099 and 0.123. This indicates a "medium" fit of the models, because usually a value above 0.2 is required for a good model fit (Gautschi, 2010). For both dependent variables, the R^2 seems to be considerably higher when interactions are added to the model,

suggesting that the interactions do improve the explanatory power of the models. For testing if the models are significantly improved by adding interaction terms, two additional LR-tests are carried out, comparing the interaction models with the models without interactions. Both tests show a significant result, hence the interactions do improve model fit significantly. In addition to the coefficients, a table of marginal effects was created (Appendix F). The marginal effects usually are a useful tool for accessing the strength of the effects of the independent variable. The value of the marginal effect is approximately the increase/decrease in probability the $P(Y_i = 1)$ for a one unit increase of the independent variable (Kennedy, 2003, p. 266). The hypotheses rely on interaction effects and hence must be analyzed using the output of the interaction models. Since the interpretation of interaction coefficients is often ambiguous, interaction plots are used for analyzing the interactions.

Table 6: Regression results

	(1) radical_inno	(2) radical_inno	(3) increm_inno	(4) increm_inno
deg_open_medlow	0.831***	0.119	0.994***	0.152
deg_open_medhigh	0.688***	0.259	0.656***	-0.204
deg_open_high	0.477	-0.690	0.896***	-0.263
co_type	0.0987	0.205	0.0809	0.657***
vertical_coop	0.227	0.142	-0.0544	-0.708*
horizontal_coop	-0.0473	-0.193	-0.175	-0.575
diagonal_coop	-0.0116	-0.316	-0.0827	-0.629
crisis	-0.535***	-1.187***	-0.696***	-1.369***
tech_h	0.542*	0.555*	0.671**	0.670**
tech_l	0.597*	0.601*	0.547*	0.532*
kis_h	0.315	0.332	0.622**	0.649**
ln_firmsize	0.0535	0.0600	0.0358	0.0418
RD_exp	5.511***	5.493***	4.205**	4.303**
target_mkt	0.275***	0.266***	0.175**	0.174**
east	-0.185	-0.187	0.293**	0.301**
crisis_deg_open_medlow		1.185***		1.388***
crisis_deg_open_medhigh		0.683		1.453***
crisis_deg_open_high		1.660**		1.690**
vertical_coop_crisis		0.205		1.045**
horizontal_coop_crisis		0.256		0.624
diagonal_coop_crisis		0.518		0.897*
crisis_co_type		-0.226		-0.937***
_cons	-1.909***	-1.490***	-1.444***	-1.016***
N	1054	1054	1054	1054
Pseudo R^2 (Mcfadden)	0.104	0.118	0.0994	0.123
Chi^2 LR-Test vs. Null	146.2***	164.7***	143.9***	178***
Chi^2 LR-Test vs. Previous		18.53***		34.30***

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Crisis

Hypotheses 1a and 1b predicted that overall for SMEs' product innovation performance for both, radical and incremental decreases during economic crisis. Corresponding to this, in both models 1 and 2, the coefficient of the crisis dummy is significant (1% level) and negative. Hence H1a is supported. Moreover, in both, model 3 and 4 the coefficient of the crisis dummy is significant (1% level) and negative. Hence H1b is supported too. This indicates that the crisis generally has a negative impact on the probability of radical and incremental innovation performance (Figure 1).

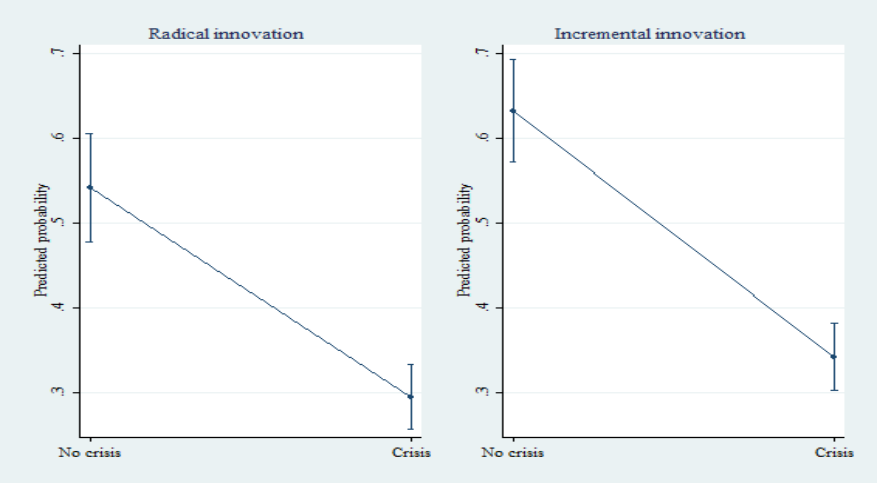

Figure 1: The effect of crisis on radical and incremental innovation probability

Degree of openness

Hypotheses 2a and 2b predict that opening up innovation activities during crisis leads to a higher likelihood of introducing radical and incremental innovations respectively. The interaction of crisis and openness in Model 2 shows significant (1% and 5% level) effects, hence there is a significant interaction for medium degree of openness and a significant interaction for a high degree of openness. The coefficients are positive, thus H2a is supported. Generally, the higher the degree of openness, the higher the respective coefficient. The interaction is visualized via the following interaction plot (figure 2). During a crisis the predicted probability of radical innovation is higher for high openness than for low openness. In the pre-crisis, the opposite is true.

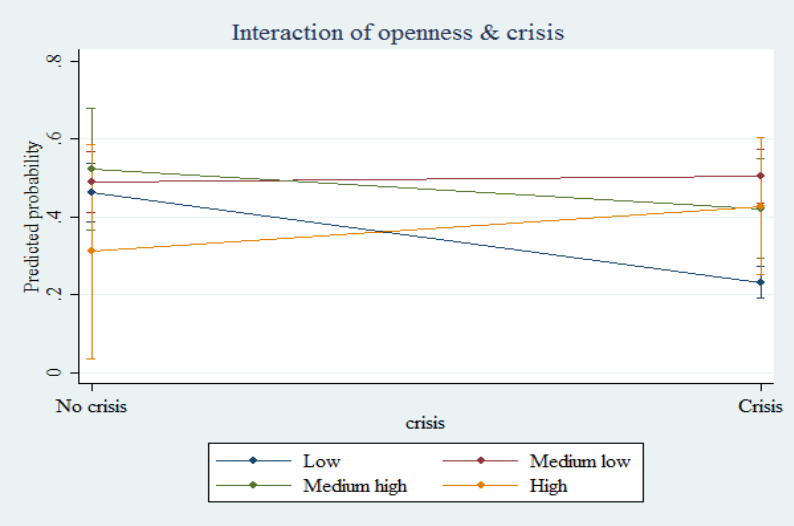

Figure 2: Interaction of degree of openness & crisis on radical innovation probability

Also in model 4, the interaction of openness with the crisis dummy is significant (1% and 5% level) with positive coefficients. The predicted probabilities in figure 3 show a very clear effect for the openness category "low". The probability for incremental innovation for the "low category" is much lower during the crisis. Also for the "high" category, the probability is higher during crisis. Hence hypothesis 2b is supported.

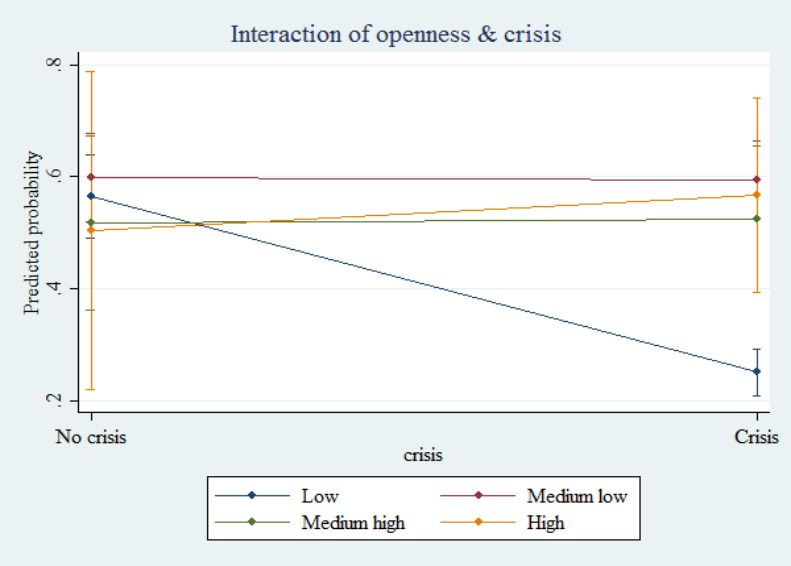

Figure 3: Interaction of degree of openness & crisis on incremental innovation probability

Co-operation types

The following hypotheses aimed at investigating the importance of specific R&D co-operation types on product innovation performance during crisis. Table 6 shows that the interaction of vertical co-operation and crisis in model 2 is not significant, hypothesis H3a is therefore not supported. Thus, no assertion about the effect of vertical co-operation on radical innovation performance during crisis can be made. However, there is a significant (5% level) interaction of vertical co-operation and the crisis dummy in model 4. The interaction plot in figure 4 shows that the probability of incremental innovation for companies that do vertical co-operation is higher during the crisis than before the crisis. Hence this H3b is supported. Next, horizontal co-operation is predicted to have a negative effect on both incremental and radical innovation performance during crisis. Since the interaction term of horizontal co-operation and crisis in model 2 is not significant, H4a is rejected. The same interference can be made from model 4, as the interaction of crisis and horizontal co-operation does not show a significant effect. Thus, hypothesis H4b is also rejected. The interaction of diagonal co-operation and crisis does not show a significant effect in model 2, thus H5a is not supported. On the contrary, the interaction of diagonal co-operation and crisis has a significant effect in model 4, but only at a 10% level, thus not supporting H5b.

Hypotheses H6a and H6b concern the effect of engaging with multiple different co-operation types simultaneously. For radical innovation performance, no assertion can be made, as the interaction of crisis and co-operation type is not significant in model 2, thus this H6a is not supported. However, model 4 indicates a significant (1% level) interaction of the crisis dummy and co-operation type, thus supporting H6b. The coefficient of the interaction term is negative, indicating that during the crisis the effect of co-operation type is significantly weaker than before the crisis. Also, figure 5 offers a very good visualization of the interaction. It shows, that before the crisis, engaging with multiple co-operation types shows a positive effect on incremental innovation probability, while during the crisis the effect is negative.

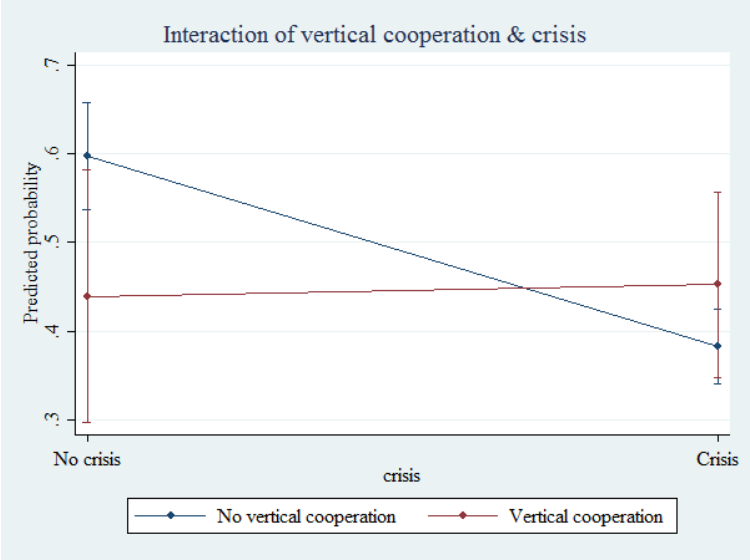

Figure 4: interaction of vertical co-operation & crisis on incremental innovation probability

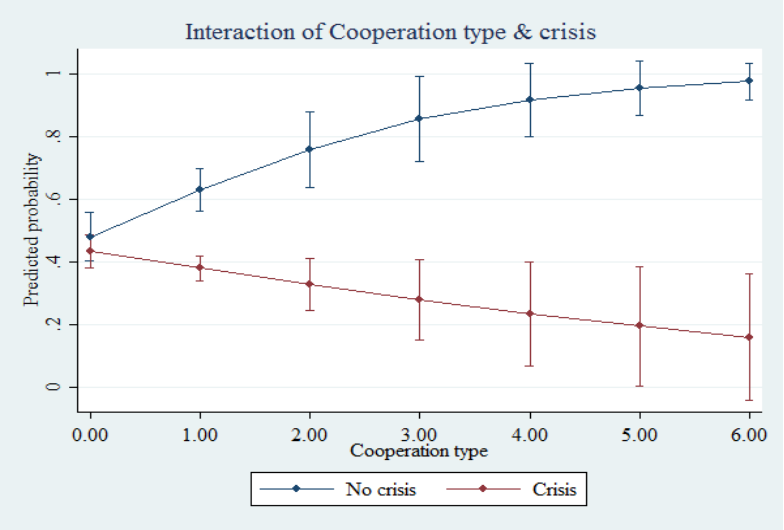

Figure 5: Interaction of co-operation type & crisis on incremental innovation probability

Control variables

A majority of control variables in all of the models are found to be significant. The industry dummies that control for the differences with regard to industry-specific effects are significant (5% level) for model 4, whereas only slightly significant (10% level) for the radical innovation performance in model 2. Surprisingly, firm size is not significant in none of the four models. However, R&D expenditures and the target market variable are highly significant in all four models (1% and 5% level). The control variable east, which controls for the geographical location of the SMEs within Germany, is only found to be significant (5% level) in model 4.

6. Discussion

Open Innovation is thought to be a universal formula for success, therefore this research aimed at investigating if a high degree of open innovation activities and more specifically OI R&D co-operation during crisis have an impact on subsequent product innovation performance, since it might be a mean for SMEs to overcome fundamental challenges of economic recessions.

The underlying analysis shows evidence for a negative effect of crisis on subsequent product innovation performance. This is in line with previous research that found out that recessions are generally impeding companies in their innovation activities (Paunov, 2012; Archibugi & Filippetti, 2011, OECD, 2012; Hud & Hussinger, 2015). Furthermore, it is interesting to mention that both, radical and incremental innovation performances are lower after economic recessions. This is also verified by the descriptive statistics which underline that both kinds of innovation are less frequent during the crisis period (table 2).

Furthermore, this study contributes to current literature, as it finds support that in general, opening up innovation activities during crisis positively affects subsequent product innovation performance (Bengtsson et al., 2015; Barge-Gil, 2010). In line with Schumpeter's theory of creative destruction (1934), it can be confirmed that smaller companies are able to realize opportunities during recessions and can reap the benefits of having a high degree of openness for subsequent innovation performance (Archibugi & Filipetti, 2011). It was expected that SMEs rather follow an exploration strategy and thus introduce specifically radical innovations. However, the results show stronger support for incremental innovation performance. Since innovation performance has been measured by the actual launch of an innovation, it could be possible that SMEs have had ideas for radical innovations, but were simply too risk-averse to actually carry them out. Results show that it makes sense for SMEs

to consider following an innovation strategy that aims at a higher degree of openness, as it is more beneficial during crisis than innovating only internally. The intention of gradually opening up to external instigators for new input can therefore be considered as an option during crisis to secure innovation performance.

The preceding analysis supports previous empirical research that revealed mixed findings about the relation between R&D co-operation and innovation performance (Bouncken & Kraus, 2013; Rosenbusch et al., 2011). Besides, new insights that extent the current stance on R&D co-operation and innovation performance can be made. Nieto and Santamaria (2007) identified vertical co-operations as most important source for improved innovation performance. This can be also confirmed for SMEs participating with vertical R&D co-operation partners during recessions. Yet, this study supports only the positive effect of vertical co-operation during crisis on incremental innovation performance. It can be argued that vertical co-operation partners only offer a limited amount of new and complementary knowledge, which makes it difficult to come up with radical innovations (Un, Cuervo-Cazurra & Asakawa, 2010). In similar vein, suppliers are often experienced in certain products that might be new to the firm but already exist in the market (Petersen et al., 2003; Primo & Amundson, 2002). Another explanation may be that even though customer co-operation can give rise to new ideas, SMEs might have difficulties to assess the implicit knowledge and transform it into radical innovations (Schweitzer & Gabriel, 2012).

Hypotheses 4a and 4b proposed that horizontal co-operation negatively impacts subsequent radical and incremental innovation performance of SMEs during crisis. In contrast to others, who stated that competitor co-operation can solve the problem of resource scarcity, this paper does not find any support for competitor co-operation (e.g. Gnyawali & Park, 2009, Ritala, 2012). Furthermore, besides the fact that the hypotheses are not supported, it is necessary to mention that the coefficients are positive and not negative as expected. Seemingly, any

possible co-operation during economic recessions has a positive probability for achieving subsequent innovation performance. One reason for the missing support might be the risk of opportunistic behavior, which is even more probable in radical innovation projects and thus stronger during times of crisis (Cassiman et al., 2009). Furthermore, as competitors engage and compete for the same market, SMEs might be even more reluctant during crisis times to transfer knowledge, in order to secure their current market position.

Belie expectations, the effect of diagonal co-operation during crisis is only slightly supported for incremental innovation performance and not supported for radical innovation performance at all. Unlike prior research that examined a general positive effect of diagonal co-operation on innovation performance (e.g. Belderbos et al., 2004; Nieto & Santamaria, 2007), diagonal co-operation seemingly impacts only incremental innovation performance. One potential reason for this is that universities tend to conduct basic research that can be too generic for SMEs to find an application in the market (Miotti & Sachwald, 2003). Furthermore, already under stable economic conditions, SMEs have problems establishing relationships with diagonal partners, as they cannot offer them sufficient research opportunities due to their limited size (Beise & Stahl, 1999). This problem could be strengthened under unstable economic conditions.

Engaging with multiple different co-operation types inherits the possibility of accessing a wide variety of different sources. However, the benefits of accessing a pool with diverse knowledge are vitiated by high costs. Unlike during stable economic conditions, engaging with numerous different co-operation types during crisis has a negative impact on incremental innovation performance. However, no assumptions can be made for radical innovation performance, as this hypothesis cannot be supported. It seems that during economic crisis, the outgoing spillover effects are greater than incoming spillover effects when engaging with a great diversity of external co-operation partners, which ultimately leads to the fact that the

costs of co-operation outweigh its gains (Laursen & Salter, 2006).

Furthermore, most control variables are relevant in explaining the effect of OI activities during crisis on subsequent innovation performance. R&D intensity is positively associated with product innovation performance of SMEs during crisis. These findings are in line with the empirical research that argues for a positive relation between R&D investments and innovation performance (Dushnitsky & Lenox, 2005). Unlike previous research, that states that company size matters (Acs & Audretsch, 1987), this study cannot make any contributions, as no support was found. In this case the liability of smallness could have some advantages during crisis, as SMEs are more flexible in terms of their size. Unsurprisingly, the industry variables are found to be relevant. However, SMEs from research- intensive industries are more likely to experience increased incremental product innovation performance than SMEs outside these industries. As high-tech industries are generally very dynamic and companies in this industry are even more surrounded by high uncertainty during crisis, they might become more risk-averse. Besides the importance of industry sectors, the geographical location of SMEs and their target market are also found to be relevant. SMEs benefit from a wider geographical target market during crisis times, as they face diverse demand and can spread the risk.

In sum, the study verifies that the recent economic crisis decreased the innovation performance of German SMEs. Generally, a higher degree of openness, compared to a closed innovation system during crisis, has a positive effect on both radical and incremental innovation performance. Evidently, incremental innovation performance is more likely to be influenced by R&D co-operation efforts during crisis than radical innovation performance. Only vertical co-operation is found to have an influence on subsequent incremental innovation performance and engaging with many different types of partners even negatively

impacts innovation performance. Potential explanations could be the costs of engaging and establishing good partner relationships and the high risk of knowledge spillovers (Cassiman & Veugelers, 2002). It seems that co-operation partners might be less willing to exchange new knowledge during economic crisis, which could potentially lead to completely new products. Furthermore, many SMEs in Germany are family firms (Klein, 2000), which are by nature rather conservative and might want to secure their heritage from bankruptcy during crisis. Moreover, it is proven that German SMEs tend to pursue innovation activities that are more driven by products that are new to the company (KfW, 2015). This study confirms that this is also true for SMEs during crisis periods, as most SMEs turn to lower-risk projects and shorter-term project (McKinsey & Company, 2009). Simply put, it can be argued that during times of recessions, SMEs tend to behave rather risk-averse regarding specific partner co-operations. Even though, a high degree of openness during crisis can lead to radical and incremental innovation performance, SMEs seem favor an exploitation strategy. Thus, as German companies were able to recover quickly, the "Sticking to our knitting" business cliché might be well-chosen strategy for SMEs to medicate recessions.

6.1. Theoretical and practical contribution

Apparently, choosing an appropriate innovation strategy is not casual, but rather a reaction of financial constraints, benefits and opportunities as well as market conditions. Thus, the choice of an innovation strategy is conditioned by specific factors. The last economic recession showed that companies generally respond to repercussions by being less willing to engage in innovation activities. However, as innovation is supposed to have a significant impact on the economy, inasmuch it can potentially pull economy out of the crisis, companies are considered to constantly bring forward new innovations. Obviously, German SMEs have been able to recover from the last economic recessions. A major theoretical contribution that can be

made is that open innovation practices and R&D co-operation during crisis are proven to impact subsequent innovation performance, specifically incremental innovation performance. Nonetheless, not all R&D co-operation types are found to be relevant. Thus, it can be a mean to overcome the economic deprivation prevalent during economic recessions but mainly for incremental innovation performance only. The findings are partly in line with the counter-cyclical argumentation that recessions foster innovation performance. However, it seems that for German SMEs, other resources, next to external sources, are of high importance as well.

The findings of this research study give new thought-provoking impulses for policy makers and interesting implications for managers of SMEs. As Hud and Hussinger (2015) pointed out, the German government implemented policies to support private R&D investments in order to make up for the reduction of private R&D. This recommendation can be extended by recommending governments to encourage Open Innovation activities and more specifically R&D co-operation during crisis. A potential possibility is implementing tax exemptions, or promoting co-operation activities by best practice cases and networking events that ultimately reduce transaction costs. When facing turbulent economic conditions, managers of SMEs should evaluate their innovation strategy by considering opening up their innovation practices and engaging in R&D co-operations, as external input can help to maintain a certain degree of innovation, even if mainly incremental innovation performance. Managers should actively look out for new opportunities, as for instance widening the target market geographically. From a co-operation strategy perspective, it is necessary to comprehend that there are also negative aspects with regard to co-operation. Especially with a broad number of different partners. Hence, if SMEs are tempted to participate in additional R&D co-operations, managers need to be aware of potential risks and keep in mind that internal innovation capabilities are important to handle external input effectively, as absorptive capacity is considered to be one of the most important constraints for SMEs (Huang & Rice, 2009). Thus,

focus is crucial in recessions and SMEs need to know how to maintain that focus and manage costs tightly next to securing growth options for the future.

6.2. Limitations and future research

Evidently, the research study is not without limitations. The study concentrates only on German SMEs, thus no general implications can be made. Therefore, future research should compare different companies within and outside the EU, focusing also on companies in countries that did not withstand the crisis well. Since this study explicitly focuses on SMEs, it might be interesting to compare results to large companies and see if there is a vast difference in outcomes. Another limitation is that only inbound OI activities were in the focus of the study, even though outbound activities might be also a potential innovation strategy for companies to pursue during crisis, as companies can nurture partner relationship and generate extra income through licensing deals (Van de Vrande et al., 2009). Open Innovation does not promise "Quick Wins". In order to successfully integrate external impulses and ideas, it is necessary to establish profound interfaces with these partners (Som, Jäger & Maloca 2014). Furthermore, it needs to be ensured that the external impulses are evaluated, transferred to internal projects and adapted according to a company's own strategy. Thus, future research should focus on these specific internal factors and investigate which strategies have to be implemented internally during crisis, that facilitate better results when engaging in OI activities.

Besides, the data has some limitations as well. Due to the nature of the survey questions, the measurement of R&D co-operation chosen for this study does not allow for the analysis of partner-specific characteristic. This might severely influence the decision-making process of SMEs for choosing a specific co-operation type during recession. Especially during crisis times, a large and established partner might be a better choice, as they are more reliable and

offer appropriate knowledge (Gnyawali & Park, 2009). It was also not possible to investigate the length and intensity of the co-operations due to the cross sectional nature of the data. A lengthy and more established relationship involves higher levels of trust, and benefits most often only materialize after a longer time period (Campbell & Cooper, 1999). The MIP questionnaires follow a common structure while the exact list of questions alters from year to year, which made it impossible to take other survey years into account, as they did not cover the questions that were relevant for the purpose of this study. Besides, it would be interesting to further investigate company specific aspects as the age of a company in the market (Aghion & Howitt, 1998) since it is argued that turbulences increase market dynamics and forces many companies to exit markets, whereas newcomers that sense opportunities enter the market.

6.3. Conclusion

All in all, this study investigated how SMEs behave during crisis times with regards to their innovation strategies, with specific focus on the degree of openness and on R&D co-operation. Open innovation practices become somewhat more important during crisis and generally opening up innovation activities has a substantial impact on radical and incremental innovation performance. Nonetheless, even though the crisis impacts the likelihood of introducing radical and incremental products to the market in subsequent years, R&D co-operation only impacts the likelihood of increased incremental innovation performance. More specifically during recessions, only vertical R&D co-operation is found to be an effective strategy. Furthermore, SMEs do not benefit from engaging with too many different co-operation partners, as costs overweight the gains. Overall, this study contends that OI activities can be a potential mechanism for SMEs to deal with economic recessions. However, SMEs should not only rely on OI practices, as there are also disadvantages associated with them.

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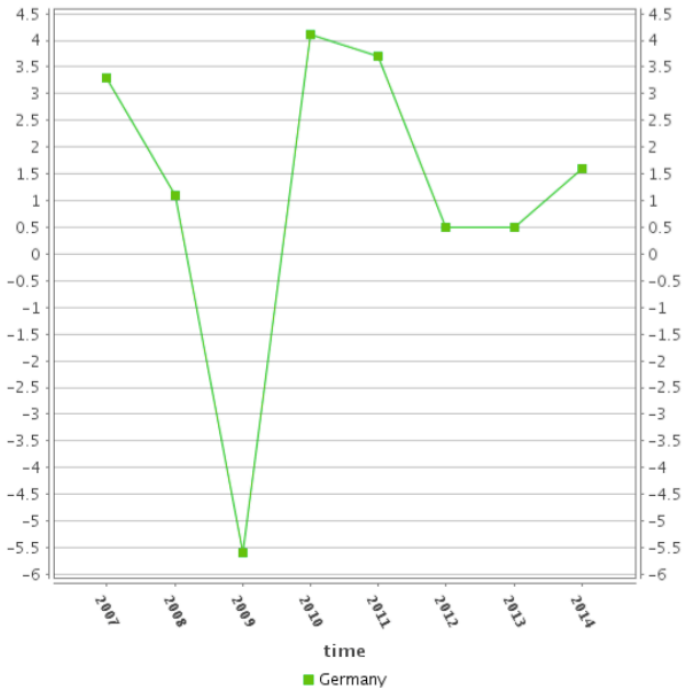
Appendix

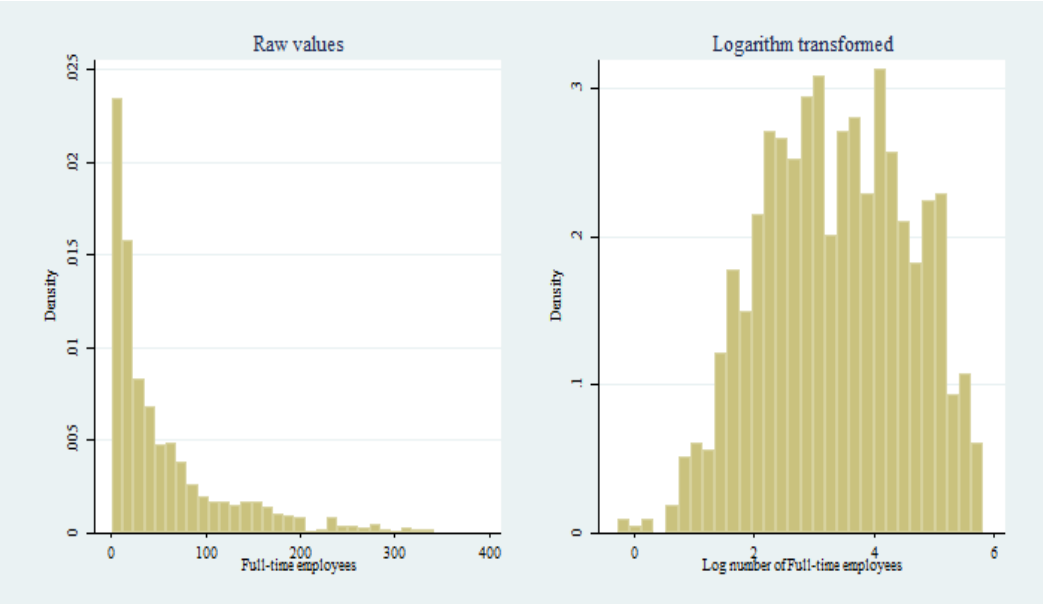
A. Real GDP growth rate – volume

The real GDP growth in Germany for the period 2007-2014 (Eurostat, 2016)



B. Logarithm- transformation

Firm size before and after log-transformation



C. Variable list

Variable	Description	Value	
	Depedent Variable		
radical_inno	Were any of the product innovations introduced new to the market (company was the first one to market these products / services)	1	yes
		0	no
increm_inno	Were any of the product innovations introduced new to the company's product range (there was no previous version of this product in the company's product line)	1	yes
		0	no
	Independent Variable		
deg_open_low*	development of product innovations carried out by company itself (internally)	1	yes
		0	no
deg_open_medlow	development of product innovations carried out together with other companies	1	yes
		0	no
deg_open_medhigh	development of product innovations carried out by adapting or modifying goods/services origianlly developed by other companies	1	yes
		0	no
deg_open_high	development of product innovations carried out by other companies	1	yes
		0	no
vertical_coop	R&D co-operation with clients or supplier on any innovation activtiy	1	yes
		0	no
horizontal_coop	R&D co-operation with competitors on any innovation activtiy	1	yes
		0	no
diagonal_coop	R&D co-operation with universities or publich research institutions on any innovation activtiy	1	yes
		0	no
co-type	R&D co-operation with various different types of co-operation partners on any innovation activtiy	1	yes
		0	no
crisis	companies within the crisis period	1	yes
		0	no
	Control Variable		
tech_h	company belongs to the high technology industry (according NACE classification)	1	yes
		0	no
tech_l	company belongs to the low technology industry (according NACE classification)	1	yes
		0	no
kis_h	company belongs to the knowledge intensive industry (according NACE classification)	1	yes
		0	no
kis_l*	company belongs to the less knowledge intensive industry (according NACE classification)	1	yes
		0	no
ln_firmsize	number of employees	numeric	transformed in logrithm
RD_exp	Total R&D innovation expenditures / total turnover	truncated at 0.15	
target_mkt	geographical target market in which the company sells goods or services	0*	local/regional within Germany
		1	national, other German region
		2	European Union
		3	all other countries
east	Companies from the "new" German Länder (former East Germany)	1	East
		0	West

* Base-category

D. Pearson correlation table

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
radical_inno	1.00																
increm_inno	0.44***	1.00															
deg_open_medlow	0.21***	0.23***	1.00														
deg_open_medhigh	0.04	0.04	-0.21***	1.00													
deg_open_high	-0.02	0.03	-0.14***	-0.06*	1.00												
co_type	0.18***	0.13***	0.22***	0.00	-0.02	1.00											
vertical_coop	0.16***	0.10***	0.17***	0.01	-0.03	0.70***	1.00										
horizontal_coop	0.08**	0.06***	0.14***	0.00	0.01	0.48***	0.23***	1.00									
diagonal_coop	0.16***	0.12***	0.18***	0.01	-0.03	0.77***	0.50***	0.29***	1.00								
crisis	-0.18***	-0.21***	-0.14***	-0.04	0.03	-0.06	-0.09***	-0.06*	-0.05	1.00							
tech_h	0.12***	0.10***	0.03	-0.03	-0.05	0.14***	0.15***	0.00	0.15***	-0.09***	1.00						
tech_l	-0.00	-0.03	0.00	-0.01	0.03	-0.10***	-0.10***	-0.05	-0.09***	-0.00	-0.52***	1.00					
kis_h	-0.06	-0.00	-0.02	0.07*	0.03	0.03	0.01	0.07*	0.01	0.05	-0.37***	-0.44***	1.00				
ln_firmsize	0.10***	0.05	0.07*	-0.03	-0.04	0.09***	0.06*	0.03	0.11***	-0.04	0.13***	0.09***	-0.22***	1.00			
fues	0.18***	0.17***	0.11***	0.04	-0.03	0.33***	0.25***	0.19***	0.35***	-0.09***	0.21***	-0.24***	0.14***	-0.06*	1.00		
target_mkt	0.21***	0.15***	0.12***	-0.04	-0.11***	0.17***	0.16***	0.08**	0.23***	-0.11***	0.37***	-0.08**	-0.18***	0.34***	0.19***	1.00	
east	0.01	0.10***	0.07*	0.05	0.02	0.23***	0.14***	0.10***	0.24***	-0.03	-0.01	0.03	0.01	-0.12***	0.25***	-0.08**	1.00

Note: * p < 0.1, ** p < 0.05, *** p < 0.01

E. VIF test

Variable	VIF
ln_firmsize	7.73
co_type	6.34
target_mkt	5.62
tech_h	3.99
tech_l	3.93
diagonal_coop	3.79
vertical_coop	2.68
crisis	2.67
kis_h	2.59
RD_exp	1.80
east	1.76
deg_open_medlow	1.69
horizontalcoop	1.50
deg_open_medhigh	1.17
deg_open_high	1.08

F. Regression table – Marginal effects

	(1) radical_inno	(2) radical_inno	(3) increm_inno	(4) increm_inno
deg_open_medlow	0.170***	0.0240	0.213***	0.0315
deg_open_medhigh	0.141***	0.0520	0.141***	-0.0424
deg_open_high	0.0976	-0.139	0.192***	-0.0547
co_type	0.0202	0.0411	0.0174	0.136***
vertical_coop	0.0465	0.0285	-0.0117	-0.147*
horizontal_coop	-0.00968	-0.0388	-0.0377	-0.119
diagonal_coop	-0.00237	-0.0635	-0.0178	-0.131
crisis	-0.109***	-0.239***	-0.149***	-0.284***
tech_h	0.111*	0.112*	0.144**	0.139**
tech_l	0.122*	0.121*	0.118*	0.111*
kis_h	0.0645	0.0668	0.134**	0.135**
ln_firmsize	0.0109	0.0121	0.00769	0.00868
RD_exp	1.127***	1.104***	0.903**	0.894**
target_mkt	0.0562***	0.0535***	0.0375**	0.0362**
east	-0.0377	-0.0377	0.0629**	0.0625**
crisis_deg_open_medlow		0.238***		0.288***
crisis_deg_open_medhigh		0.137		0.302***
crisis_deg_open_high		0.334**		0.351**
vertical_coop_crisis		0.0413		0.217**
horizontal_coop_crisis		0.0516		0.130
diagonal_coop_crisis		0.104		0.186*
crisis_co_type		-0.0454		-0.195***
N	1054	1054	1054	1054
Pseudo R^2 (Mcfadden)	0.104	0.118	0.0994	0.123
Chi^2 LR-Test vs. Null	146.2***	164.7***	143.9***	178***
Chi^2 LR-Test vs. Previous		18.53***		34.30***

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$