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Radical Innovation – A domain of SMEs?*

A novel test of the Schumpeterian Hypothesis

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Abstract

The Schumpeterian Hypothesis has been subject to a plethora of research aiming at the provision of new insights to the relationship of innovation on firm size. Utilizing a panel of German companies in manufacturing industries from 1993-2011, this analysis explicitly distinguishes between radical and incremental innovation output. It reveals that firm size and radical innovation share an overall negative relationship, while the relationship between firm size and incremental innovation is positive. These results provide a novel explanation for the often-reported non-linear relationship between firm size and innovation.

Keywords: SME, firm size, radical innovation, incremental innovation, manufacturing industry
JEL Classification: L11, O31

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1. Introduction

The relationship of firm innovation behavior in dependence of firm size has been a long debated issue. It was Schumpeter (1934) who initially advocated the notion that small firms are the cell for technological discontinuity and thus for innovation. During the next decade, Schumpeter (1942) adapted his views shifting the notion towards the abundant resource base of large firms that were thereby better able fostering innovation efforts in contrast to small firms with their limited resources. This take became known as one cornerstone of the Schumpeterian Hypothesis.

In the course of the following decades the Schumpeterian Hypothesis has been challenged by a variety of scholars and the unsolved controversy has been explicitly differentiated with influences from industrial organization as well as management theory and technology management aspects. Among these efforts has been a plethora of innovation management research targeting the definition of various forms and aspects of innovation for firms and their respective industries (Duchesneau, Cohn and Dutton, 1979). In this context, the refinement of measures for innovation, diverging from R&D expenditures and focusing on innovation output, was an important impetus that fueled the debate. New measures such as patent counts, innovation intensity or the sales of innovative products provided new insights into the firm size – innovation relationship (Bound et al., 1984; Scherer 1965a and 1965b, Schwalbach and Zimmermann, 1991). Some authors supported the Schumpeterian view (Soete, 1979), while others either found a negative (Rothwell, 1989) or a non-linear relationship (Kamien and Schwartz, 1975). Also the incorporation of industry characteristics such as its technological advancement and the degree of competition facilitated unveiling the Schumpeterian Hypothesis (Acs and Audretsch, 1987 and 1991). Yet, the empirical results cannot provide conclusive evidence on the relationship and its influencing factors.

Acknowledging the long lasting debate about the ideal circumstances to nurture innovation, this study provides distinct empirical analyses on radical as well as incremental innovation behavior with respect to firm size. In essence, the study is going to reveal particular behavioral differences among innovation output types in dependence of firm size. Thereby, it provides an empirically tested novel explanation for the researched and proven non-linear relationship between overall innovation output and firm size which is in essence a composite effect of radical and incremental innovation sales behavior. Hence, this paper is going to contribute to the economics of innovation regarding the firm size – innovation relationship that has struggled to deliver robust results. Bearing in mind that any kind of result is strongly dependent on time and industry characteristics, this study focuses on German manufacturing industries that have an unparalleled reputation to be continuous innovation leaders in their respective industries.

The sample comprises German manufacturing companies taking part in an annual innovation survey during the years 1993 until 2011. It includes more than 40,000 firm-year observations from about 8,900 companies. Radical innovation thereby will be explicitly distinguished from incremental innovation efforts by means of sales figures of market innovations vs. improved products.

The results reveal that firm size negatively influences radical innovation. In contrast, incremental innovation is positively related to firm size. In consequence, overall innovation output and firm size share an inverted U-shaped relationship with a maximum innovation output for firm sizes of about 1,054 employees confirming earlier findings of Scherer (1965a) and Kamien and Schwartz (1975). The findings advance a novel explanation of the relationship in that the sum of radical and incremental innovation amounts to a composite effect causing the non-linear relationship of total innovation output and firm size. It also contrasts the Schumpeterian Hypothesis whereupon large firms are most conducive to especially radical innovation. Furthermore, it supports the findings of Bound et al. (1984), Schwalbach and Zimmermann (1991) as well as Acs and Audretsch (1987) that firm size does not generally grant advantages in generating innovation output. Finally, the analysis proves that radical innovation is still a domain of SMEs in German manufacturing industries.

The paper is structured as follows. The next chapter provides an overview of the relevant literature regarding firm size and innovation. The subsequent chapter introduces the dataset utilized followed by the results of the empirical analysis. The final section concludes the chapter with a discussion of the results and its implications.

2. The relationship of firm size and innovation

The relationship of innovation and firm size has received ample scholarly attention from a variety of streams of economic research (Brown and Eisenhardt, 1995). Among these are organization theory, economics, entrepreneurship and also industrial organization.

Several studies support the Schumpeterian Hypothesis concluding that firm size is conducive for innovation arguing that the process of innovation is endogenous to large firms with their abundant resource bases and thus cannot be assumed by outsiders (Galbraith, 1956; Schumpeter, 1942, Symeonidis, 1996). Soete (1979) confirms the Schumpeterian view in finding that for US companies, R&D expenses increase with firm size. His pooled sample included 500 US companies. Scherer (1991) shows that for the US more than 90% of all R&D is conducted among the largest 400 companies. Also, Scherer (1992) in his analysis states that large firms are more likely to support R&D programs and file for patents. Moreover, when only considering the sub-sample of companies that in fact invest into R&D or are granted patents, the aforementioned innovative activities rise linearly with firm size (ibid.). Yet, most of the (especially) early studies suffered from an aggravating shortcoming by limiting the analysis to R&D expenditures as the sole measure for innovation input (Audretsch and Vivarelli, 1996; Symeonidis, 1996).

With the introduction of direct measures of innovation output such as patents or marketed innovations, the Schumpeterian Hypothesis has been increasingly challenged. Critics of Schumpeter advanced the notion that small firms are better able market innovation since they do not have to overcome structural and administrative burdens to launch a novel product and simultaneously do not face a competitive situation for the allocation of resources with a multitude of existing products (Chandy and Tellis, 2000; Ghemawat, 1991). In two studies Scherer (1965a, 1965b) used a sample consisting of 448 firms of the top 500 US companies to run regression analyses to measure R&D employment intensity and patents on sales as innovation drivers in dependence of firm size. For R&D employment intensity an inverted U-shaped relationship is found, whereas the patent count rises less than proportional with firm size. Both results were interpreted to reject the Schumpeterian Hypothesis, as there is no positive influence of firm size and innovation activity (Symeonidis, 1996). Rothwell (1989) used commercialized innovations in the United Kingdom (UK) as a measure to prove that the number of innovations in fact decreases with firm size.

Bound et al. (1984) in their regression analysis as well as Schwalbach and Zimmerman (1991) showed that small firms have a disproportional high share in patents in the US and West Germany. Bound et al. (1984), using a comparably large sample of US firms, find that small as well as large firms share a higher R&D intensity than do medium-sized companies, essentially describing a U-shaped relationship. The OLS regression results are robust regarding a potential selection bias since the results of the samples with and without firms not reporting R&D activities are almost identical. Also Pavitt, Robson and Townsend (1987) find a non-linear, U-shaped relationship with small and very large firms (>10,000 employees) to be most successful innovators. In their regression analysis they utilized innovation intensity (R&D expenses divided by the number of employees) as the dependent variable.

Acs and Audretsch (1987) systematically analyzed the relationship under consideration of different market conditions utilizing the US Small Business Administration database and using innovation intensity (i.e. the number of innovations divided by the number of employees) as their dependent variable in multiple regressions. They concluded that firm size and innovation output overall share a negative relationship with a variety of exceptions and devoted their attention to industry characteristics that fuel the relationship. In monopolistic markets with high entry barriers, strong unionization, high capital-intensity and the production of differentiated products, large firms are better able to foster innovation. On the contrary, in industries that are highly innovative, have a significant share of large firms, and rely to a great extent on skilled labor, smaller firms tend to have an advantage regarding innovative output. Audretsch and Acs (1991) in another study found that innovative performance does not increase with firm size for high-technology companies utilizing innovation counts as the dependent variable and including fixed-effects at the industry level in their regression. Symeonidis (1996) summarizes the various research findings and concludes that innovation input (i.e. R&D expenses) tends to rise with firm size, whereas smaller firms produce more innovations than large firms in relation to their innovation input. Recent research among European manufacturing industries regards large firms as better able to launch innovation efforts across all industries (Vaona and Pianta, 2008).

However, none of the above mentioned studies explicitly distinguish between the different types of innovation on the output side. In essence, the lack of a dominant logic that has not evolved until today might be due to the shortcoming that most studies do not differentiate between different degrees of innovation. Most studies focus on innovation output in general, very few studies focus on radical innovation, yet there is no comparison included that expresses a relation between radical and incremental innovation with regard to firm size. Therefore, this analysis will extend previous approaches and conduct separate analyses for radical as well as incremental innovation output. Since both types of innovation are distinctly different in that they require different technological capabilities and organizational structures to be nurtured, a different dependence of firm size can be expected (Chandy and Tellis, 2000; Henderson, 1993; Laursen and Salter, 2006).

As radical innovation is one particular form of innovation, its implications should be distinguished thoroughly as it requires different abilities and circumstances to be optimally nurtured. Daft and Becker (1978) define radical innovation as a new technology that is not only novel to the company but simultaneously also to the entire market and thereby diverges from existing practices. In a systematic effort, Foster (1986) depicted the evolution of radical innovation efforts with the theory of the S-curve.[1] In essence, radical innovation is characterized by providing a new, differentiated technology to the market that has substantial benefits for its customers and thus has an impact beyond the firm level (Chandy and Tellis, 1998; Garcia and Calatone, 2002). Mansfield (1981) showed that R&D expenditures that are devoted to entirely new products or processes rise less than proportional with firm size. In another early attempt, Ettlie and Rubenstein (1987) found that for companies with up to 1,000 employees there is no significant relationship regarding radical product innovation output with increasing firm size. For firms employing 1,000-11,000 employees there is an increase in radical product innovation output with increasing firm size. Hence, the relationship is of non-linear nature. Chandy and Tellis (2000) find a negative linear relationship between firm size and radical innovation in their multivariate regression analysis with a reversal of the relationship during the 150-year time span under consideration. The analysis focused on 64 innovations of the consumer durables industry around the world.

In contrast to radical innovation, incremental innovation focuses on the firm level and adopts or improves an existing technology in an existing market (Chandy and Tellis, 2000; Garcia and Calatone, 2002). It requires less effort to bring to market and its implications are therefore minor to radical innovation output (Marsili and Salter, 2005). Furthermore, organizational routines are a trigger and booster for incremental innovation, while these same routines are considered detrimental to development of radical innovation (Chandy and Tellis, 2000). Min,

[1] The theory is a derivative from technology management and shows how a radically new technology supersedes an incumbent technology over time (Foster, 1986; Sahal, 1985; Utterback, 1994).

Kalwani and Robinson (2006) state that incremental innovators have a lower risk of failing with an incrementally innovated product than with radical innovation. Dewar and Dutton (1986) were the first to distinguish between radical and incremental innovation output. Nonetheless, the analysis only focused on the indirect dependence on firm size since the adoption of radical and incremental innovation technologies is central to their analysis. Moreover, it is focused on process rather than product innovation. In the small-scale study of 40 US footwear manufacturers they find a positive relationship of firm size and the adoption of radical innovation, whereas they cannot detect a similar or reverse effect for incremental innovation adoption. Laursen and Salter (2006) find that incremental innovation is positively related to firm size, while radical innovation and firm size do not share a significant relationship. However, their analysis included firm size[2] (logarithm of employees) only as a control variable.

2.1 The difficulty for large firms to (radically) innovate

Schumpeter's early work on innovation suggests that small firms should have advantages in introducing product innovation. According to his view, small firms are the key innovating source in a society by enabling technological discontinuities (Schumpeter, 1934). This perspective is furthered in that increasing firm size can even hamper the introduction of new products or services. For one, this circumstance is attributed to the theory of inertia, which finds strong support in research (Cohen, 1995; Hannan and Freeman, 1984; Scherer, 1991). Generally, large firms have substantial administrative staffs and procedures in order to ensure an efficient conduct of business. However, this formalization of business proves to be difficult for the introduction of radical innovations since they require an adaption to new routines and administrative procedures for the firm. In addition, individual ideas are often marginalized in larger firms since it is more difficult for an employee to draw attention to his or her innovation due to the existing and multitudinous administrative layers. An additional obstacle can be the focus on the existing network the firm has established it in. Hill and Rothaermel (2003) argue that the presence of this network exacerbates radical innovation since firms do not want to jeopardize their relationship with investors and customers due to a new approach that initially cannot promise any value creation. This line of argumentation is further progressed by adding that industry incumbents and large firms do not necessarily only underinvest in innovation but allocate their resources inefficiently regarding innovation as

[2] Laursen and Salter (2006) define the size control variable as the logarithm of the number of employees.

they predominantly make significant investments into existing products and markets (Ghemawat, 1991). Focusing on radical innovation, Henderson (1993) supports the argumentation by adding that industry incumbents often approach specifically radical innovation with underinvestment (Henderson, 1993).

In general, the process of innovation has shifted from being achieved within a single firm to a multitude of stakeholders that facilitate, drive and support the innovation process (Chesbrough, 2003). Accompanying this shift, the concept of open innovation has increasingly drawn attention. Initially, open innovation was focusing on large technology companies (West, Vanhaverbeke and Chesbrough, 2006), although earlier research already indicated that SMEs were equally able to utilize external influences to their advantage and thus to overcome structural disadvantages such as a weaker financial position. Audretsch and Vivarelli (1994) showed that small firms are better able to utilize external knowledge sources, especially universities, than large firms. This R&D spillover effect is present in the US as well as in Europe and is significantly stronger for small firms than for corporations. In German manufacturing industries, R&D cooperation is utilized complimentary to the innovation process (Becker and Dietz, 2004). In an exploratory study focusing on manufacturing companies, Keizer, Halman and Dikstra (2002) found that SMEs are as innovative as large firms when they are able to secure government grants, and devote a substantial part of their resources to R&D. With regard to radical innovation there is also support for the precedent stance that firm size does not positively influence radical innovation efforts and thus neglecting a size advantage for large firms (Cohen, 1995; Lauren and Salter, 2006). In summary, it can be expected:

H_1: Firm size and radical product innovation share a negative relationship by which decreasing firm size increases radical innovation output.

2.2 The challenge for small firms to innovate

Following the Schumpeterian Hypothesis, large firms are better able to foster innovation efforts due to the larger resource base (Schumpeter, 1942). Continuing on that perspective, the resource-based view on firms suggests that large firms shall be better off to realize innovative efforts due to their resources, not only financially but equally important due to their skilled labor and availability of existing R&D as well as distribution structures (Lee et. al., 2010).

With abundant resources, large firms can afford to explore new paths in product development without necessarily being dependent on the success of the development since its routine operations can be running independently. Additionally, the large resource base allows financing R&D activities for a mid- to long-term horizon, which is often a necessary requirement for successful innovations since breakthrough applications often undergo development phases of more than 15 years and cannot be realized without the continuous capital commitment of a sponsor (cf. Khilji, Mroczkowski and Bernstein (2006) for development times in the biotech industry).

As a pre-condition to financing R&D activities large firms do not face the same capital (market) constraints as their smaller counterparts. For start-up companies and SMEs the cost of capital is generally higher due to their weaker financial position in terms of asset base, revenues and profits. Therefore, external financing of innovative activities, which is a high-risk investment by default (regardless whether equity or debt), is more costly and demands higher risk premium payments for small firms (Cohen and Levin, 1989; Hall and Lerner, 2010).

Another important advantage that large firms can realize is its structural adaption to nurture innovation efforts. Large corporations increasingly decentralize their core business and grant comprehensive levels of autonomy to independently operating business units (Chandler, 1956; Williamson, 1975). This structural aptitude can grant advantages of small firms and yet lets the business unit appreciate the resource advantages of a large corporation (Chandy and Tellis, 2000). Taking into consideration specifically European manufacturing industries, Vaona and Pianta (2008) find that large firms consistently outperform SMEs in product as well as process innovation. For German manufacturing industries Becker and Dietz (2004) confirm this notion, advocating the greater experience and efficiency of large firms to successfully bring innovations to the market.

In contrast to radical innovation efforts, incremental innovation in fact is nurtured by existing organizational routines (Chandy and Tellis, 2000). With its concomitant explicit focus on existing technologies, incremental innovation effort can more easily be integrated into running operations (Marsili and Salter, 2005). As a result, organizational inertia, regarded as disadvantageous for the launch of radical innovation efforts (Cohen, 1995), appears to be a fruitful driver of incremental innovation in that it can rely on already existing processes and technologies. Additionally, since large firms to a great extent rely on their existing network and avoid jeopardizing its ties with customers and suppliers (Hill and Rothaermel, 2003), incremental innovation efforts fit well into their concept, since it relies on existing technologies that require little adaption (Marsili and Salter, 2005). As a consequence, the risk of failure for incremental innovation efforts is reduced due to the reliance on existing technologies and the associated known customer benefits (Min, Kalwani and Robinson, 2006). Extending the perspective of H_2, it can be hypothesized:

H_2: Firm size and incremental product innovation share a positive relationship by which increasing firm size increases incremental innovation output.

2.3 The composite effect of radical and incremental innovation

Aside of the discussion whether firm size positively or negatively influences innovation behavior, a variety of scholars described a non-linear relationship between firm size and innovation efforts. Scherer (1965a) found that for medium-sized companies, R&D employment intensity was highest concluding that being very large in terms of sales is not an essential condition to conduct successful R&D. In fact, firm size beyond a certain threshold hampers innovative activity. Kamien and Schwartz (1975) furthered this perspective of the inverted U-shaped relationship by adding that for input as well as output, firm size only to a certain point is conducive for innovation. The perspective initiated by the aforementioned authors is based on a variety of reasons supporting the relationship. First, in contrast to small firms, more medium-sized companies have a greater financing security regarding innovation, which grants the ability to finance simultaneous high-risk R&D projects[3] (Brown, Martinsson and Petersen, 2010; Lopez-Gracia and Aybar-Arias, 2000). Second, administrative layers among more medium-sized companies are not as sophisticated as it will be among large firms, thus keeping the organizational inertia in levels that still grant the opportunity to meaningfully conduct innovation projects offside the formalized process levels (Hannan and Freeman, 1984, Pelham, 2000). Third and most importantly, innovation output cannot be regarded as a homogeneous measure, but has to account for the distinct types it is comprised of (Dewar and Dutton, 1986; Ettlie, Bridges and O'keefe, 1984). The underlying notion behind this rationale, is the awareness that radical and incremental innovation output, which are the essential parts

[3] For large companies, financial constraints are even less evident regarding R&D (see Hall & Lerner, 2010)

of total innovation output[4], are diverse in their very nature and thus require different environments in order to be optimally furthered (as described in H_1 and H_2). As a consequence, a composite effect of radical and incremental innovation will essentially determine the overall innovation output behavior in relation to firm size. Since incremental innovation tends to increase with firm size, while radical innovation decreases with firm size, a non-linear relationship will best capture the overall innovation output – firm size relationship. In summary, it can therefore be hypothesized:

H_3: Firm size and overall product innovation share a non-linear, inverted U-shaped relationship as the sum of the individual radical and incremental innovation behavior.

3. Data and descriptive statistics

The underlying dataset is based on the annual German innovation survey conducted by the Centre for European Economic Research (ZEW). The Mannheim Innovation Panel (MIP) collects innovation data for German industry and service sectors since 1993 and is the German contribution to the Community Innovation Survey by the European Union that has been established to monitor the innovation behavior of firms across the European Union. It has to be noted that the CIS and thus also the MIP follows the guidelines of the OSLO manual that sets internationally accepted guidelines on the collection of innovation data from businesses (OECD, 1997)

The underlying study focuses on manufacturing companies within the MIP from 1993 until 2011. All service-oriented firms have been omitted form the dataset. The data are anonymized in order to protect company identities and hence an allocation from company fundamentals to its identity is ruled out. Since the analysis utilized time-series, only companies that have been observed at least twice during the time span are included in the final sample. The sample consists of 40,086 firm-year observations from 8,939 different companies.

3.1 Dependent variables

The dependent variable of this study measures the innovation sales intensity of the observed firms. The underlying MIP survey asks the participating companies to split their sales into

[4] Since only product innovations are taken into consideration in the underlying analysis, process innovations are not taken into account.

distinct classes regarding the innovativeness of their products. These classes are whether the product is entirely new to the market, new to the companies' portfolio or do only feature minor or no changes and improvements. Since the focus of this study is on radical and incremental product innovation, market novelties as well as novelties to the companies' portfolio are taken into consideration. The survey classifies the share of radical/incremental innovation on total sales on a scale from 0 to 9 reflecting the percentages in the following way:

Table 1 about here

Furthermore, also total innovation sales as the sum of radical and incremental innovation output will be analyzed[5]. The dependent variables are labeled *Radical*, *Incremental* and *Innototal*.

3.2 Independent variables

The independent variable measures firm size by means of employees. Since the distribution of the number of employees is skewed, the logarithm as well as the squared logarithm is utilized in the analysis as independent variables in order to check for a non-linear relationship as well (*logSIZE* and *logSIZEsq*).

Several control variables are included in the dataset. R&D intensity is controlled for by the ratio of R&D expenses over total revenue (*Intensity*). Moreover, a dummy variable is added in case the company is located in Eastern Germany since the reunification of Germany characterized by a dissimilar development of both parts of the country (*East*). Finally, a full set of year dummies is included for every year of the sample (*Year*).

3.3 Descriptive statistics

31,190 (77,8%) of the observations are from small and medium-sized enterprises with 45.2% small companies less than 50 employees and 32.5% medium-sized companies. 8,896 (22,4%) are from large firms with more than 250 employees, resulting in overall 40,086 total observations[6]. Table 2 provides an overview of the descriptive statistics for the sample.

[5] This definition also ensures that no other innovation efforts, such as process innovations are accounted for.
[6] The cut-off points for a distinction between small-, medium-sized and large enterprises follow the current definition of the European Union (European Commission, 2005).

While the overall average radical innovation activity is about 1.03 (equaling about 5% of total sales), the ratio for large firms is higher than for SMEs. Large firms have an average radical innovation intensity of 1.41 (about 7.5% of total sales), whereas SMEs account for 0.93 (less than 5% of total sales). For incremental innovation, the overall average intensity equals 2.73 (about 13% of total sales), with SME intensity of 2.52 (10%), whereas for large firms the incremental innovation rate equals 3.48 (17.5%). Regarding innovation intensity, SMEs spend on average about 4.7% on innovation, whereas large firms only expense 4.5% averaging 4.7% for the entire sample. This finding does not come surprising, as innovation spending does not linearly increase with firm size (Becker & Dietz, 2004).

Table 2 about here

4. Empirical results

One of the key questions of this analysis is whether firm size has a significant impact on radical innovation performance and if there is an obvious behavioral difference of the relationship in contrast to incremental innovation output. The underlying dataset comprises a total 19 years with repeated observations of the same firms. Due to the panel structure of the data set, a fixed-effect regression is utilized to analyze the effect of firm size on radical and incremental innovation performance because a fixed-effect model controls for the time-invariant characteristics of each firm (Torres-Reyna, 2011).

Table 3 shows the results of the three estimations with the dependent variables radical, incremental and total innovation sales for the fixed-effect regression in columns one to three including all sampled years from 1993-2011.

Table 3 about here

The first estimation reveals a negative and significant relationship of firm size on radical innovation output, signaling the growing firm size hampers radical product innovation sales. The fixed-effect regression supports H_1, revealing a negative relationship of firm size and radical innovation with a significant coefficient for *logSIZE*, while *logSIZEsq* is insignificant and thus supporting the findings as advocated by Cohen (1995) and Laursen and Salter (2006). For the estimation, only companies that in fact have radical innovation output have been analyzed.

The control variables for the radical innovation fixed-effect regression reveal that innovation intensity is positively significant meaning that higher levels of innovation input lead to higher levels of radical innovation output, which does not come surprising. Moreover, the east dummy is significant in the model showing that Eastern German companies strongly engage in radical innovation effort, contrasting the results of Czarnitzki, Dick and Hussinger (2010) who found that Eastern German firms are less innovative than their Western counterparts regarding radical innovation. However, the focus of the aforementioned analysis has been on a different sample exclusively observing young venture companies with less than 50 employees founded after 1990 (Czarnitzki, Dick and Hussinger 2010). The year dummies are significant and positive expect for the years 2004 and 2006-2009.

In contrast to radical innovation, incremental innovation overall is positively influenced by firm size confirming H_2. The coefficient of *logSIZE* is positive and significant while the square term *logSIZEsq* remains insignificant, signaling a positive linear relationship of firm size and incremental innovation. Again, also the innovation intensity variable is positive and significant, whereas the East dummy remains insignificant contrasting the results from the radical innovation regression and also the analysis of Czarnitzki, Dick and Hussinger (2010) who found a positive relationship of Eastern German companies on incremental innovation for their sample of German ventures. The year dummies reflect mixed results with the years 1994-1996, 1998, 2001, 2004-2005, 2007 and 2010 being positive significant, whereas the other years remain insignificant.

Considering total innovation output of the sample comprised of radical and incremental innovation, an inverted U-shaped relationship becomes evident. Both size variables *logSIZE* and *logSIZEsq* are significant, while *logSIZEsq* reveals a negative coefficient. The maximum is at about 1,054 employees revealing that large firms with about 1,000 employees have the highest overall innovation output with several companies employing more than 1,000 employees in the sample. This result substantiates H_3 and the early analyses of Scherer (1965a) as well as Kamien and Schwartz (1975) who detected a similar general innovation output behavior in dependence of firm size where neither small nor very large firms are the best drivers of innovative activity and thus neglecting a linear relationship. Figure 1 graphically summarizes the three estimation progressions in dependence of firm size for the fixed-effect regression.

In accordance with the separate fixed-effect regressions for radical and incremental innovation, the innovation intensity is positive and significant. The *East* dummy remains insignificant similar to the incremental innovation result and therefore supports the previous analysis of Czarnitzki and Kraft (2006) stating that firms in Eastern Germany tend to be less innovative than its Western counterparts due to their transition into a market economy from 1990 onwards. All year dummies are significant as well, whereby the coefficients turn negative from 1997 until 2011.

Figure 1 about here

4.1. Robustness check

Another way to control for firm-specific effects in panel data is to utilize a pre-sample mean of the dependent variable. Similar to the approach of Blundell, Griffith and Van Reenen (1999), the fixed-effect regression models are re-estimated including a pre-sample estimator of the dependent variable for the time period covering 1993 until 1995. Based on their earlier fixed-effect model proposition (Blundell, Griffin and Van Reenen, 1995), Blundell, Griffin and Van Reenen (1999) showed that the pre-sample mean approach to fixed-effects is valid for regression estimations and therefore can be used to control for firm-specific time-invariant effects in a panel.

Table 4 shows the regression results of the regression analysis utilizing the pre-sample mean of the respective dependent variable (radical, incremental and total innovation output). The results confirm the negative relationship of radical innovation and firm size, while the coefficient is smaller when adding the pre-sample mean estimator. Regarding incremental innovation, the regression coefficients of *logSIZE* and *logSIZEsq* indicate an inverted U-shaped relationship. Nonetheless, the inflection point of the curve is within the 99th percentile of the firm size distribution. In essence, the finding thus confirms the linear relationship of firm size and incremental innovation. Also for total innovation output, the inverted U-shaped relationship with firm size is confirmed. *logSIZE* as well *logSIZEsq* are highly significant.

For all three estimations innovation intensity also remains positively significant. The dummy for Eastern Germany is also significant in all three estimations. However, for all the estimations it turns negative indicating a negative impact of companies located in Eastern Germany towards innovation output. The year dummy variables for radical innovation are significant only for 2003-2006 as well as for 2008-2010 and share a negative coefficient. For incremental innovation, all years are significant expect 2001 and 2005 and total innovation output is significant in all sampled years.

Table 4 about here

5. Discussion and conclusion

Innovation in dependence of firm size has been a widely discussed topic since the early days of innovation research (Schumpeter 1934 and 1942). The Schumpeterian Hypothesis, emphasizing the resource base advantage of large firms vitally invigorating innovation, has been challenged by a variety of different research streams (Bound et al., 1984; Scherer, 1991 and 1992; Rothwell, 1989; Schwalbach and Zimmerman, 1991) focusing on the output side of innovation rather than the mere input side equitable to R&D related measures. Nonetheless, research has not established a dominant logic regarding the optimal firm size where innovation is best nurtured. Acs and Audretsch (1987) put the discussion into the context of industry characteristics as one important cornerstone to consider the debate within. Another reason among others for a non-existing dominant logic might have been the lack of distinction between different the degrees of innovation, i.e. radical vs. incremental innovation in this regard.

This paper analyzed the firm size – innovation relationship for German manufacturing industries form 1993 until 2011 by distinctly separating between different degrees of innovation. The focus has been on the difference between radical and incremental innovation output by means of relative sales. Moreover, also the total innovation output of firms has been included in the analysis. The empirical results reveal that over the course of two decades, firm size negatively influences radical innovation. The finding is in line with the results of Acs and Audretsch (1987) stating that in highly innovative industries with a significant share of large firms, smaller firms have an advantage with regard to innovation output. It therefore contradicts the Schumpeterian Hypothesis upon which large firms have an advantage in introducing radical innovation due to the abundant resource base (Schumpeter, 1942).

For incremental innovation, the pattern is different than for radical innovation confirming the stance that it is a necessary analytical prerequisite distinguishing the two majorly different types of innovation. In contrast to radical innovation, incremental innovation among German manufacturing industries is positively related to firm size. This finding is in line with the advocates of resource-emphasized perspective (Lee et. al., 2010) as well as the notion that financing of innovation is more difficult for smaller companies (Hall and Lerner, 2010).

Regarding total innovation output, the previous findings hint to an interconnection impact of radical and incremental innovation to a non-linear, inverted U-shaped relationship with firm size. The optimal overall innovation output level is reached for companies with about 1,000 employees. This result can be regarded as a composite effect where the sum of radical as well as incremental innovation output (which are both distinctly different) amount to the overall innovation output curve with its particular inverted U-shape. It thus provides a novel explanation as to why the innovation – firm size relationship is of non-linear nature and furthermore substantiates the early findings of Scherer (1965a) and Kamien and Schwartz (1975).

Although, the optimal size by definition is larger than medium-sized companies, it still is significantly smaller to regard this optimal firm size level as equal to a major corporation. Also, the finding challenges the Schumpeterian Hypothesis in that size is only conducive to innovations up to a certain threshold and beyond that impede innovation output.

The findings have several implications. First, the general innovation output in German manufacturing industries is a product of the distinctly different radical and incremental innovation behavior. Second, as a consequence, this implies that innovation output has to be carefully distinguished and cannot be treated as a homogeneous measure. Radical innovation has different prerequisites in German manufacturing industries than incremental innovation. While incremental innovation is best nurtured with increasing firm size, radical innovation decreases with firm size. Hence, measures to actively support one or the other mode of innovation should first answer the question which degree of innovation shall in fact be furthered. Third, radical innovation still is a domain of SMEs in German manufacturing industries. Traditionally, German SMEs have been the backbone of the economy and account for a substantial part of the economic performance and innovation activity. 54% of German SMEs introduced innovations while the R&D budget strongly increased from 2004-2010 by 71%[7] (Federal Ministry of Economics and Technology, 2014). These values are strongly above international average. Hence, the SME advantage regarding radical innovation is partly rooted within the German economy, where SMEs account for 52% of total economic output. On the other side, incremental innovation, requiring less effort and relying on organizational routines is best nurtured within large firms. Hence, the adoption of existing technologies into a companies' portfolio seems to be easier with more resources and established organizational routines.

It has to be acknowledged that this study has certain limitations. First, the measure of innovation only captures those projects that have been successfully marketed while neglecting any failed innovative efforts. Given the high-risk nature of any innovative activity, the proportion of discontinued and unsuccessful innovation projects is likely to be significant. Unfortunately, the sample and construction of the MIP survey does not allow measuring radical vs. incremental innovation as an input variable. Second, the analysis does not measure behavioral changes over the panel since there are no adequate variables available to effectively capture and define potential evolutionary changes. Third, a detailed separation between sub-industries has not been possible due to the necessary removal of any time-invariant firm characteristics in the analysis. Although German manufacturing industries can be well regarded as highly innovative, a more sophisticated approach would have benefited the analysis in order to draw stronger industry-specific conclusions as advocated by Acs and Audretsch (1987).

[7] For large firms the increase has been 19%.

6. Tables

Table 1: Scale of revenue with new to market/business products / total sales

Value	1	2	3	4	5	6	7	8	9
% of total sales	<5	<10	<15	<20	<30	<50	<75	<100	<100

Source: Mannheim Innovation Panel: Guide to the survey's datasets for external users, 1993 to 2011 surveys

Table 2: Descriptive Statistics

	SMEs (N=31,190)				Large firms (N= 8,896)			
Variable	Mean	SD	Min	Max	Mean	SD	Min	Max
Radical	0.93	1.85	0	9	1.41	1.88	0	9
Incremental	2.52	2.80	0	9	3.48	2.47	0	9
Innototal	3.29	4.14	0	18	4.83	3.88	0	18
logSIZE	3.49	1.23	-1.26	6.16	6.50	1.02	4.85	12.33
logSIZEsq	13.69	8.36	0.00	37.90	43.28	15.07	23.55	152.06
Intense	0.05	0.80	0	0.35	0.04	0.06	0	0.35
East	0.37	0.48	0	1	0.15	0.36	0	1

Note: Year dummies are omitted

Table 3: Fixed-effect regression estimations

Model	Fixed-Effect Regression Model		
Dependent variable	Radical innovation Coef.	Incremental innovation Coef.	Total innovation Coef.
logSIZE	-0.33*	0.30***	0.41***
	(0.19)	(0.10)	(0.15)
logSIZEsq	0.01	-0.01	-0.03*
	(0.02)	(0.01)	(0.02)
Intensity	1.00**	7.06***	9.86***
	(0.45)	(0.38)	(0.61)
East	0.83**	-0.25	0.10
	(0.32)	(0.26)	(0.37)
Year1994	0.67***	0.80***	0.77***
	(0.15)	(0.11)	(0.22)
Year1995	0.58***	0.91***	1.16***
	(0.15)	(0.11)	(0.23)
Year1996	0.51***	1.05***	0.00
	(0.16)	(0.12)	(.)
Year1997	0.34**	0.15	-1.14***
	(0.15)	(0.10)	(0.16)
Year1998	0.56***	0.23**	-0.89***
	(0.14)	(0.10)	(0.16)
Year1999	0.72***	0.04	-0.88***
	(0.14)	(0.11)	(0.17)
Year2000	0.54***	0.16	-0.76***
	(0.14)	(0.11)	(0.17)
Year2001	0.58***	0.36***	-0.51***
	(0.13)	(0.11)	(0.18)
Year2002	0.59***	0.03	-1.00***
	(0.14)	(0.11)	(0.18)
Year2003	0.22*	0.17	-1.03***
	(0.14)	(0.11)	(0.18)
Year2004	0.09	0.22**	-1.15***
	(0.13)	(0.11)	(0.18)
Year2005	0.26**	0.57***	-0.64***
	(0.13)	(0.11)	(0.18)
Year2006	-0.05	0.18	-1.21***
	(0.13)	(0.11)	(0.18)
Year2007	0.06	0.24**	-1.05***
	(0.12)	(0.11)	(0.18)
Year2008	-0.07	0.12	-1.29***
	(0.11)	(0.11)	(0.18)
Year2009	-0.13	0.12	-1.29***
	(0.10)	(0.11)	(0.18)
Year2010	-0.36***	-0.31***	-1.87***
	(0.10)	(0.11)	(0.18)
Year2011	0.00	0.13	-1.22***
	(.)	(0.11)	(0.18)
_cons	4.02***	1.31***	3.08***
	(0.53)	(0.28)	(0.40)
#	8243.00	27231.00	24127.00
ll	-12049.46	-48660.40	-51239.49
p	0.00	0.00	0.00

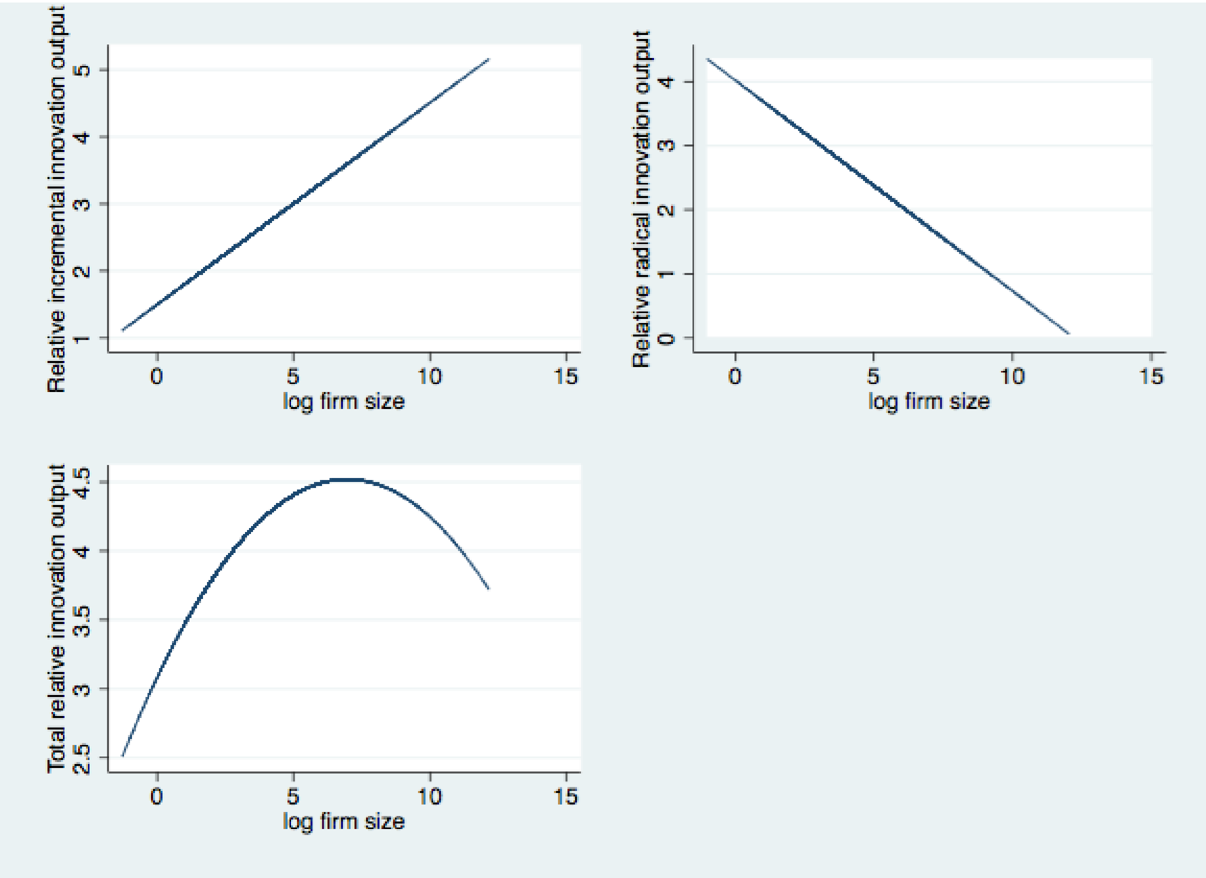
*** (**, *) indicate a significance level of 1% (5%, 10%)

Table 4: Pre-sample mean estimator

Model	OLS Regression Model with Pre-Sample Mean Estimator		
Dependent variable	Radical innovation Coef.	Incremental innovation Coef.	Total innovation Coef.
logSIZE	-0.17**	0.49***	0.79***
	(0.09)	(0.05)	(0.13)
logSIZEsq	0.01	-0.03***	-0.05***
	(0.01)	(0.01)	(0.01)
Intensity	1.65***	7.96***	12.44***
	(0.42)	(0.30)	(0.78)
East	-0.16**	-0.20***	-0.51***
	(0.08)	(0.05)	(0.12)
Pre-Sample Mean	0.59***	0.51***	0.49***
	(0.02)	(0.01)	(0.01)
Year1996	-0.13	0.56***	-0.46**
	(0.13)	(0.10)	(0.24)
Year1997	-0.09	-0.45***	-1.77***
	(0.13)	(0.09)	(0.22)
Year1998	-0.04	-0.40***	-1.64***
	(0.13)	(0.09)	(0.22)
Year1999	0.13	-0.51***	-1.21***
	(0.13)	(0.10)	(0.23)
Year2000	-0.20	-0.46***	-1.63***
	(0.14)	(0.10)	(0.24)
Year2001	-0.00	-0.17	-0.68**
	(0.15)	(0.11)	(0.28)
Year2002	0.04	-0.73***	-1.93***
	(0.16)	(0.11)	(0.25)
Year2003	-0.41**	-0.36***	-1.88***
	(0.17)	(0.11)	(0.26)
Year2004	-0.67***	-0.39***	-1.87***
	(0.20)	(0.13)	(0.29)
Year2005	-0.54***	0.04	-1.43***
	(0.20)	(0.13)	(0.31)
Year2006	-0.57**	-0.68***	-2.49***
	(0.23)	(0.14)	(0.31)
Year2007	-0.29	-0.49***	-2.05***
	(0.23)	(0.15)	(0.34)
Year2008	-0.42**	-0.49***	-2.38***
	(0.21)	(0.14)	(0.31)
Year2009	-0.82***	-0.44***	-2.21***
	(0.22)	(0.15)	(0.33)
Year2010	-0.87***	-1.08***	-2.64***
	(0.22)	(0.15)	(0.33)
Year2011	-0.25	-0.66***	-1.83***
	(0.24)	(0.16)	(0.36)
_cons	1.98***	-0.23	0.46
	(0.26)	(0.15)	(0.38)
#	2614.00	9875.00	4132.00
ll	-4824.23	-21614.87	-10893.77
p	0.00	0.00	0.00

*** (**, *) indicate a significance level of 1% (5%, 10%).

Figure 1: Predicted values of incremental, radical and total innovation output



Fixed-effect regression model with predicted values of dependent variables incremental, radical and total innovation output

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