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Contingency Factors and the Technology-Performance-Relationship in Start-ups

Arne Schmidt, Sascha G. Walter und Achim Walter

Abstract

This study identifies the pace of technological development and market heterogeneity as crucial environmental conditions shaping start-ups' performance when commercializing radical technologies. Using a unique dataset that combines survey and patent data for 85 technology-based start-ups, we found that technological radicalness has a positive effect on performance when the development pace in a start-up's technological field is high. Contrarily, under heterogeneous market conditions, technological radicalness diminishes a start-up's performance. The results emphasize that the impact of technological radicalness on start-ups' performance is context specific. Overall, these findings contribute to a better understanding of when technological radicalness represents an asset or a liability for technology-based start-ups.

1 Introduction

Previous empirical research has focused on the suitability of technological inventions for exploitation through firm formation (Henderson, 1993; Shane, 2001a). These studies point out that firm formations based on radical technologies are assumed to be an adequate exploitation mechanism and should outperform start-ups with less radical technologies. But bringing radical technologies into commercial application valued by the market is a complex and risky process not yet fully understood (Jensen & Thursby, 2001; Prebble, de Waal, & de Groot, 2008). For radical technological inventions, value-creating applications are initially abstract (Popper & Buskirk, 1992) and firms need to understand customer needs to convert these technologies into valuable products (Lynn, Morone, & Paulson, 1996; Popper &

Buskirk, 1992). It is therefore unclear if radical technologies provide favorable opportunities for firm formation.

Entrepreneurship literature states that the technological and industrial environment shape the conditions under which start-ups have to overcome the barriers (Maine & Garnsey, 2006) and critical junctures in their commercialization process (Vohora, Wright, & Lockett, 2004). To exploit the economic potential inherent in technological inventions, start-ups need appropriate environmental conditions (Agarwal & Bayus, 2002; Bstieler, 2005; Gans & Stern, 2003; Wiklund & Shepherd, 2003). Technology life-cycle theory holds that the suitability of firm formation to commercialize technological inventions changes over time. Dynamic phases with technological improvements are expected to be favorable for young firms since technological standards are not yet established and niche markets provide opportunities for firm formation (Shane, 2001b; Tushman & Anderson, 1986). Finding a niche market with customers who have a high willingness to pay for products based on technologies that are not fully developed, is a crucial condition for successfully introducing technologies to the market when technological radicalness is high (Adner & Levinthal, 2001). Moreover, the applicability of technologies for distinct possible applications in different industries is high for radical technologies and start-ups exploiting these technologies face the strategic decision, which markets to enter (Gans & Stern, 2003; Gruber, MacMillan, & Thompson, 2008). Since linking technologies to a market is time and resource consuming and commercialization effort is high, radical technology start-ups need clear-cut customer demands and market conditions to efficiently concentrate their commercialization effort.

We therefore posit that the performance of technology-based start-ups is a function of the technological radicalness, which is moderated by the pace of development in the start-up's technological environment and the heterogeneity of the entry markets. To test our arguments, we draw upon a unique dataset of 85 German technology-based start-ups combined with assigned patent data. In the light of increasing managerial and political interest in technology commercialization through firm formation, this paper helps to explain outcomes of commercialization efforts across different industries. We contribute to the understanding of how value creation from technological inventions can be achieved and under which environmental conditions firm formation is an appropriate way of doing so (Daneels, 2004). This study therefore contributes to entrepreneurship and technological life-cycle theory alike.

Major practical implications can also be drawn for start-up management with regard to the nexus between the degree of technological radicalness as well as the market entry strategy and technology transfer policy of publicly funded research institutions.

The paper is organized in the following sections: Section 2 briefly reviews the literature on radical technologies, arguing that technological radicalness impacts a start-ups' performance and how certain environmental conditions interact with this relationship. Section 3 describes the data, variables used in the analyses and methodology employed for testing the hypotheses. Section 4 presents the results of the regression models. Finally, section 5 concludes and draws implications for theory, policy and start-up management.

2 Theory and Hypotheses

In the Schumpeterian (1934) framework, the invention of new technologies is an exogenous event, wiping out the equilibrium in the market. Technological progress enables the recombination of resources in a new and value-creating way and provides opportunities for entrepreneurs to bring new technologies to market (Schumpeter, 1942). Consequently, technological progression forms the basis for competition across industrial sectors. Established and new firms alike can benefit from proprietary technological knowledge which allows for competition on the basis of differentiation (Acs & Audretsch, 1988). Radical technological inventions have received particular interest since these are the drivers of technological progress and bear the potential to induce fundamental changes in markets (Tushman & Anderson, 1986).

Technological radicalness refers to the technological content of an invention and describes the distance of technological paradigms new inventions built upon (Dahlin & Behrens, 2005; Rosenkopf & Nerkar, 2001). Hence, radical technological inventions combine existing pieces of technological knowledge from distinct domains and introduce it to a new technological domain or scientific community (Fleming, 2001; Green, Gavin, & Aiman-Smith, 1995). It is important to distinguish the pre market entry technological characteristics from a technologies post market entry outcome, referred to as technological disruptiveness (Dahlin & Behrens, 2005; Govindarajan & Kopalle, 2006). Technological disruptiveness

describes the extent of technological changes in a given market and the degree of displacement of existing technologies (Christensen, 1997; Christensen & Bower, 1996). The disruptiveness of a technology depends on the trajectories of competing technologies and can therefore only be measured *ex-post*. Hence, it has no predictive power for estimating technological potential (Daneels, 2004). To prevent these circularity problems when testing factors contributing to commercialization success, we utilize the concept of technological radicalness to test our hypotheses (Sood & Tellis, 2005).

Technological radicalness has been studied in various streams of academic literature. Studies focused on the antecedents of radical technologies and processes of creating radical technological knowledge (Fleming, 2001; Rosenkopf & Nerkar, 2001), sources of radical technologies such as private firm research and universities, the assigned technology transfer mechanisms (e.g. Ahuja & Lampert, 2001; Colyvas et al., 2002; Henderson, Jaffe, & Trajtenberg, 1998; Trajtenberg, Henderson, & Jaffe, 1997), the importance of radical technological inventions for technological progress and change (e.g. Dolata, 2009; Dosi, 1982; Popper & Buskirk, 1992) and commercialization processes leading to value creation (e.g. Colyvas et al., 2002; Nerkar & Shane, 2003; Shane, 2001a). However, the complex process of technology commercialization is still ambiguous, which is particularly true for radical technologies (Iansiti, 1997). While some studies state that technological radicalness enhances the competitive position of start-up firms and imply better performance prospects (Henderson, 1993; Shane, 2001a), contrary arguments about the radicalness-performance relationship exist. Referring to the embryonic nature of radical technologies, studies state that the matching process of technology to market opportunities is challenging (Jensen & Thursby, 2001; Popper & Buskirk, 1992) and pursuing these opportunities is time and resource consuming (Bond & Houston, 2003; Shane & Stuart, 2002).

A central condition for bringing new technologies to market through firm formation is the pace of technological development. Literature on technological development states that technologies follow a life cycle (Ford & Ryan, 1981). Empirical evidence shows that the paths of technology development are scattered with periods of rapid technological improvements followed by periods of no improvements (Andersen, 1999; Sood & Tellis, 2005; Tushman & Anderson, 1986). During the phases of technological improvements, different technological paradigms with different development trajectories compete to become

the technological standard and niche markets evolve (Cimoli & Dosi, 1995; Dosi, 1982; Freddi, 2009). These niche markets provide the possibility for market entrance of newly established firms (Adner, 2002; Adner & Zemsky, 2005). We therefore posit that the impact of technological radicalness on start-ups' performance is moderated by the pace of technological development in the start-ups' technological fields.

Further, radical technologies offer a wide range of possible applications with differing economic potential (Jensen & Thursby, 2001; Maine & Garnsey, 2006). Firms face the crucial strategic decision of which applications for a technology to pursue and which markets to enter to realize the highest economic value. Studies showed that having a broader set of market opportunities for choice proved to be beneficial for start-ups (Gruber et al., 2008). However, pursuing market opportunities for technological inventions is a resource intensive undertaking while start-ups usually face a resource deficit at their setout (Shane & Stuart, 2002; Walter, Auer, & Ritter, 2006). Linking technologies with a high degree of radicalness to market opportunities is even more resource consuming because the technological uncertainty is high and substantial investments are needed to develop products of services based on the technology (Green et al., 1995). Hence, entering heterogeneous markets and serving distinct customer demands is an ambitious opportunity exploitation strategy for start-up firms when technological radicalness is high.

2.1 Radical technologies and start-up performance

The relation of the radicalness of a start-up's technology and its performance is not straight forward. Nerkar and Shane show that technological radicalness contributes to start-up survival only in segmented markets (Nerkar & Shane, 2003). Moreover, the commercial potential of radical technologies is initially uncertain (Jensen & Thursby, 2001), value-creating applications abstract (Popper & Buskirk, 1992) and the feasibility of certain business models based on the technology is insecure (Bond & Houston, 2003). Consequently, many technology-based start-ups fail to create substantial wealth (Lockett & Wright, 2005) and technological life-cycle literature states that the most successful commercialized technological breakthroughs originate from large firms (Sood & Tellis, 2005).

Another common position in academic literature claims that radical technologies are a fertile ground for firm formations. Therefore, firms based on radical technologies should

outperform their counterparts based on less radical technologies (Rosenbloom & Christensen, 1994). Four arguments have been put forward to underpin this position.

First of all, established firms are in an advantageous position for exploiting incremental technological inventions since these draw on the capabilities and resources that established firms already possess (Christensen & Bower, 1996). When commercializing radical technologies, established firms lack these advantages since new technical and commercial skills are needed (Tushman & Anderson, 1986) which are difficult and costly to create (Henderson & Clark, 1990). Second, established firms are at risk of cannibalizing their own business models when commercializing radical technologies (Chandy & Tellis, 1998). Established firms have therefore less incentive to invest in the exploitation of radical technologies undermining their own technological assets. Third, established firms evaluate the economic potential and possible applications of a technology in the light of customer needs they currently face (Pavitt, 1984; Rosenbloom & Christensen, 1994). But future customer needs are the relevant benchmark for evaluating economic potential of technology as customer needs change over time (Bower & Christensen, 1995; Christensen & Bower, 1996; Dougherty, 1990). Start-up firms do not face this threat and evaluate technologies and their possible applications from an unbiased perspective. Hence, start-up firms have a competitive advantage when exploiting radical technologies. Last, radical technologies offer a wide range of different applications across industries and hence provide various market opportunities (Haupt, Kloyer, & Lange, 2007; Jensen & Thursby, 2001; Maine & Garnsey, 2006). Having a more diverse choice set of opportunities proved to be advantageous for firm formations based on technological developments and contributes to their market performance (Gruber et al., 2008). We therefore expect a positive impact of technological radicalness on the market performance of start-up firms, concluded in Hypothesis 1:

Hypothesis 1: The more radical the technological invention, the better the market performance of technology-based start-up firms.

2.2 Pace of technological Development

The pace of technological development refers to patterns of change in technological fields and describes the frequency of technological improvements (sometimes also referred to as 'technological turbulence', e.g. Jaworski & Kohli, 1993). Literature on technological

development states that the evolution of radical technological inventions often starts in publicly funded research institutions. As basic research is conducted and first thresholds are overcome, more researchers and firms from the private sector become interested in the technology and begin to develop the technology further (Pavitt, 1984; Popper & Buskirk, 1992; Walsh, 1984). Consequently, the pace of technological development increases and firms begin to enter markets with products and services based on the technological inventions (Dosi, 1982; Haupt et al., 2007). As technology matures, markets get saturated, the rate of new firms entering the market declines as technological standards emerge and the pace of technological development slows down (Gort & Klepper, 1982; Sood & Tellis, 2005).

Empirical evidence showed that the period of frequent market entry by firms and product advancement antecedes the sales takeoff for inventions introduced to market (Agarwal & Bayus, 2002). This period of rapid technological development therefore offers the best prospects for generating revenues by technology commercialization through firm formation. The technology is already well known in the market and different research groups believe in its economic potential and commit themselves financially to the technology. Hence, newly established firms commercializing the technology have favorable conditions to overcome the liability of newness, gain legitimacy and enter markets successfully (Carayannopoulos, 2009; Garud & Rappa, 1994).

Moreover, periods of rapid technological development are characterized by the emergence of niche markets and the absence of clear-set technological standards (Tushman & Anderson, 1986). Customers in these niche markets often employ different performance criteria for a new technology and are willing to pay for crude products based on radical technologies (Adner, 2002; Adner & Levinthal, 2001). Achieving market entry allows firms to receive feedback from the market, develop the products further and adopt them to market needs (Lynn et al., 1996). Niche markets are therefore a fertile ground for first market entry based on merely embryonic and radical technologies.

The establishment of technological standards leads to product standardization, and the basis of competition among firms shift from differentiation to costs (Utterback & Abernathy, 1975). Thus, absence of technological standards allows firms to compete on the basis of technological differentiation (Garud, Jain, & Kumaraswamy, 2002) and the competitive advantages of established firms due to economies of scale and learning curve effects diminish.

Periods of rapid technological development can therefore be assumed beneficial for the first introduction of radical technologies to markets through firm formations as technological standards typically are not yet set. This suggests the following hypothesis:

Hypothesis 2: The environmental pace of technological development positively moderates the relationship between technological radicalness and the market performance of technology-based start-up firms.

2.3 Market-Heterogeneity

Radical technologies can be used in different applications and form the basis for market entry across distinct industries (Haupt et al., 2007; Jensen & Thursby, 2001; Maine & Garnsey, 2006). They allow for a more diverse choice set how many market opportunities to pursue and which markets to enter (Gruber et al., 2008). It is therefore a fundamental decision of entrepreneurs in technology-based start-ups; how many and which markets to enter and which possible applications to pursue. This market entry decision determines the market environment of the start-up, which may be segmented into market segments with varying characteristics and needs that should be served, referred to as market heterogeneity or complexity (Wiklund, Patzelt, & Shepherd, 2009). The market heterogeneity is described by the diversity in customers' buying habits, the nature of competition and market dynamism and uncertainty (Miller & Friesen, 1982; Newkirk & Lederer, 2006). For technology-based start-ups, entering heterogeneous markets is an unfavorable strategic choice for commercializing radical technologies. Two arguments can be put forward to underpin this position.

First, value creating applications for radical technologies are initially abstract and start-ups exploiting radical technologies need to gain access to market information and learn about the industrial requirement on products based on the technology (Lynn et al., 1996; Popper & Buskirk, 1992). In heterogeneous environments, these firms need to cope with a multitude of information about customer needs, competitors and their strategies and product requirements for different market sections (Goll & Rasheed, 1997; Newkirk & Lederer, 2006). This increases the information processing demands for a firm when filtering and assimilating the crucial information needed for product development (Heeley, King, & Covin, 2006).

Moreover, it complicates decision-making processes in the firm (Miller & Friesen, 1983). Consequently, more heterogeneous markets make it harder for start-up firms to meet customer needs when commercializing radical technologies with initially abstract value creating applications (Zahra, Neubaum, & Huse, 1997).

Second, the commercialization of technology is a time and resource consuming task. This holds especially true for radical technologies because their technological uncertainty is high and substantial investments are needed to develop products of services based on these kinds of technology (Green et al., 1995; Zucker, Darby, & Armstrong, 2002). As heterogeneous markets demand a more diversified product development (Zahra, 1996; Zahra et al., 1997), the resource requirements for market entry increase further with higher market heterogeneity (Dess & Beard, 1984; Robinson & McDougall, 2001). Start-ups are usually constraint in their resource endowments and securing sufficient resources to pursue the designated market opportunities is a central challenge for these firms (Shane & Stuart, 2002; Walter et al., 2006). Heterogeneous markets may therefore be a disadvantageous environment for start-ups commercializing radical technologies. Thus, we posit:

Hypothesis 3: The environmental market heterogeneity negatively moderates the relationship between technological radicalness and the market performance of technology-based start-up firms.

3 Methods

3.1 Sample and data collection

Universities are a rich source for technological inventions, contributing significantly to technological progress and driving macroeconomic growth (Henderson et al., 1998; Jaffe, 1989). Different channels for the commercialization of these university-affiliated inventions exist, including the creation of new firms (Doutriaux, 1987). Technological inventions from public research institutions may be of an embryonic and radical nature (Jensen & Thursby, 2001; Rosenberg & Nelson, 1994; Steffensen, Rogers, & Speakman, 2000). Start-ups based on these technologies therefore represent an adequate objective for studying

commercialization success of firm formations based on technologies with varying degrees of radicalness. For our study, we considered start-ups formed to exploit technology from publicly funded research institutions in Germany, including universities, universities of applied science, and research institutions within the Fraunhofer Society, Helmholtz Association, Leibniz Science Association, and Max-Planck Society (see Krabel und Müller, 2009 for a description). The level of analysis is the individual organization. As key informants, we identified the founders of the firms because they are involved in technological issues and management issues alike.

In 2004 and 2005, we collected contact information for technology-based start-ups in Germany from technology transfer offices, print media, the internet and annual reports from research institutions. Between 2005 and 2006, we contacted 542 start-ups and arranged 288 face-to-face interviews with a member of the founding team. When the firms were contacted via telephone to arrange a meeting for the interview, we secured that (1) the business model is based on a technological inventions developed by the founders in the public research institution and (2) the interviewee is a member of the founding team. Subsequently, trained interviewers conducted the interviews based on a standardized questionnaire.

Afterwards, we matched the names of all members of the founding teams and the name of the start-ups with patent applications in the database "PATSTAT" (version 09/2008) provided by the European Patent Office. Patent applications were assigned to start-ups if they were filed during a 3-year period, ending with the year the respective start-up was incorporated. We received 139 complete set of questionnaires and patent application data. In addition, we had to exclude spin-offs for this study for the following reasons. Firstly, some firms failed to give answers to questions used in the analyses. Secondly, firms were excluded if they were older than 10 years (Song, Podoyntsyna, van der Bij, & Halman, 2008). Thirdly, if firms had not entered the market with a product or service based on their technology, two years before the survey was conducted. In the final analyses, data were complete from 85 start-ups. A profile of the sample depicts a reasonable spread across technological fields, including biotechnology (31%), electronics (29%), nanotechnology/new materials (18%), software/simulation (14%) and others (8%). The average age of the firms were 5.5 years and the average number of full-time staff was 15.4, which is comparable with other studies in this field (Hmieleski & Baron, 2009; Nerkar & Shane, 2003; Walter et al., 2006).

3.2 Measures

The scale development followed guidelines of Rossiter (2002). The measures were either developed specifically for this study or adapted from past research to suit this context (e.g. Miller & Friesen, 1982). All scales were pre-tested in three successive rounds. In each round, two to three interviewees (founders of start-ups based on technology from publicly funded research institutions) were asked to complete the questionnaire. While completing the questionnaire, the respondents discussed any thoughts that came to mind. The items were revised following each round of interviews. At the end of round three, the feedback from the respondents indicated that the scale items were clear, meaningful, and relevant. The complete measurement scales are included in the appendix.

Additionally, we employed a patent based measure for technological radicalness, which has been used in various prior studies (Nerkar & Shane, 2003; Rosenkopf & Nerkar, 2001; Shane, 2001a). By collecting data from different sources, we enhance the measure validity and reduce the threat of common method variance.

3.2.1 *Dependent variable*

As recommended in the entrepreneurship literature, we considered growth in sales as a traditional accounting measure of firm performance (e.g. Brush & Vanderwerf, 1992; Chandler, McKelvie, & Davidsson, 2009; Chesbrough, 2003; Lee, Lee, & Pennings, 2001; Short, McKelvie, Ketchen, & Chandler, 2009). Growth in sales is an adequate measure for commercial success as it shows the market's acceptance of a start-up's commercialized technology. We gathered information on the sales figures for the three years before the interview took place and calculated the geometric growth rate for these two periods. If firms were only in operation during the two previous years, we employed the same methodology for one growth period. Because our sales growth data were not normally distributed, we used a natural log transformation.

3.2.2 Predictor variables

Prior research has reasoned that using patent data to empirically assess the technological content of an invention is a valid approach (Dahlin & Behrens, 2005). We therefore measure *technological radicalness* by means of patent data. We gathered all patent applications assigned to the start-ups and their founding team during a three-year period ending in the year of the start-up's set-out. Using the patent family information from the PATSTAT database (Version 09/2008), we grouped all patent applications into families. A patent family consists of all patent applications based on the same invention in different jurisdictions¹. Grouping equivalent patent applications into families prevents the threat of counting the same invention multiple times in our data (Lettl, Rost, & von Wartburg, 2009).

Radical technological inventions are more likely to cite patents from other patent classes than from the ones the inventions itself belongs to (Rosenkopf & Nerkar, 2001), therefore combining different pieces of technological knowledge (Fleming, 2001). Based on this idea, we measure the radicalness of a patent family as a time-invariant count of the number of three-digit 'international patent classifications' (IPC) in which previous patents cited by the focal patent family are found but the focal family itself is not assigned to (Nerkar & Shane, 2003; Shane, 2001a). As the level of analysis in our study is the individual organization, we measured a start-up's technological radicalness as the average of its assigned patent families. Because the variable was not normally distributed, we used a natural log transformation.

The *pace of technological development* in a firm's technological field was measured using a scale developed based on drivers of pace of technological development as described by Sood and Tellis (2005). The instrument is comprised of five items requiring respondents to indicate the extent of their agreement with each item using a seven-point Likert-type scale anchored by (1) "does not apply at all" and (7) "applies fully and completely". The mean score, calculated as the average of the five items, assesses the pace of technological change in a start-up's technological domain at the time of the firm's foundation. The measurement scale

¹ To be considered as part of the same DocDB simple family, a patent application has to claim exactly the same priority applications. There may be exceptions from this rule if the European Patent Office classifies a patent application to a DocDB simple family due to face validity.

describes the extent of research conducted in the specific technological field and its frequency of technological progress. The Cronbach's coefficient alpha of the scale was 0.82.

The scale for measuring *market heterogeneity* was adapted from Miller and Friesen (1982) and consisted of three items² on a seven-point Likert-type scale anchored by (1) "rather similar for all products" and (7) "varies strongly between products". The mean score was calculated as the average of the three items and describes the diversity of environmental conditions regarding customer characteristics, competition, and market changes at the time the survey was conducted. The Cronbach's coefficient alpha of the scale was 0.85.

3.2.3 Control variables

Founders of start-ups need time to start and develop their organization, and the commercialization of technological inventions is a time-consuming process. Roberts (1990) shows that technology-based start-ups are likely to change their business priorities over time. For example, established start-ups may have decided not to grow over a certain size. Therefore, we controlled for the *age of the start-ups*. As large organizations have more resources to conduct R&D and force product development, we controlled for the *size of the start-ups* and measured it as the number of total employees. Firms founded by individuals with previous start-up experience may have an advantage relative to firms with inexperienced founding teams. Start-up experience enhances the skills of how to lead and develop an early-stage organization and how to develop products based on technological inventions (Brüderl, Preisendörfer, & Ziegler, 1992). We constructed a dummy variable, *start-up experience*, which is coded 1 if at least one member of the founding team had previously founded a company. The *engagement of venture capitalists* in a start-up's equity can enhance its performance since VCs provide financial resources, start-up and business experience and an industrial network (Hsu, 2007; Wright, Lockett, Clarysse, & Binks, 2006). We controlled this by using a dummy variable which is coded 1 if one or more venture capitalists hold a stake in a start-up's equity. Start-up firms may also profit from patenting its technological inventions since patents provide protection from imitation (Colyvas et al., 2002; Teece, 1986), signal technological competence, help to build legitimacy in the market (Blind, Edler, Frietsch, &

² One of the original items was dropped because it does not fit the context of start-up firms.

Schmoch, 2006; Fontana, Geuna, & Matt, 2006) and can be used as exchange currency in relationships with external partners (Blind et al., 2006). Patents can therefore help to realize the economic potential of technological knowledge assets (Granstrand, 1998; Mansfield, 1986). We therefore controlled for the *size of the patent portfolio* and considered the number of patent families assigned to a start-up or one of its founders during a three-year period ending in the year of the start-up formation. We further controlled for the *technology field* of the start-ups' core technologies (dummies). Mansfield (1995) found that different scientific disciplines vary in their impact on industrial innovation. In a similar vein, Klevorick et al. (1995) demonstrated that technological fields are differently well connected to a range of industries. Consequently, resources needed for the exploitation of technological inventions and time-to-market differs greatly across technological fields.

3.3 Analytical procedures

We relied on hierarchical moderated regression analysis to test our hypotheses, as suggested by Aiken and West (1991) and Jaccard et al. (1990). To reduce multicollinearity between the interaction terms and independent predictor variables, the main effect variables were centered prior to the computation of the interaction terms (Aiken & West, 1991). We calculated the variance inflation factor (VIF) and the condition index (CI) for all models to check for multicollinearity problems. The highest VIF across all models amounts to 1.82 for 'nanotechnology/new materials' in model 3. The highest CI totals up to 11.67 in model 3. The values of multicollinearity indicators therefore are below the suggested guidelines (Cohen, Cohen, West, & Aiken, 2003) and multicollinearity does not seem to be a problem.

In step 1 we entered the control variables into the regression model. The independent predictor variables were entered in step 2, followed by the interaction terms in step 3. For the main and interaction effects, regression coefficients and the change in R^2 were examined to test the significance of direct and interaction effects.

4 Results

Table 1 provides descriptive statistics and bivariate correlations among the variables used in the regression analyses.

Insert Table 1 about here

Significant correlations exist between three of the technology field dummies and independent predictor variables. It appears that biotechnology start-ups face on average a higher pace of technological development, whereas nanotechnology/new material start-ups encounter slower paces of technological development. Biotechnology start-ups also enter on average less heterogeneous markets. Moreover, experienced start-up teams exploit on average less radical technologies and start-ups facing fast technological developments are on average bigger in size. All correlations appear to be weekly significant and moderately strong. All other correlations between the independent variables remain insignificant. Table 2 reports the results of the hierarchical regression analyses.

Insert Table 2 about here

All models are significant and indicate a satisfactory level of explanation of the performance variable (adjusted R^2 of .18 - .27). Model 1 indicates that of the set of control variables, start-up age has a strong negative influence on sales growth whereas the involvement of venture capitalists has a positive effect. In model 2, technological radicalness interestingly shows no significant positive effect on performance, as expected in Hypothesis 1. Thus, Hypothesis 1 receives no support. In model 3 we introduced the interaction terms which show both statistically significant effects on the sales growth measure. The interaction of technological radicalness and pace of technological development has a positive impact on

sales growth, whereas the interaction of technological radicalness and market heterogeneity has a negative impact. The change in R^2 for the contingency versus main effect model is statistically significant.

To add further interpretation, we plotted the relationship of technological radicalness and sales growth for low (minus one standard deviation from the mean) and high (plus one standard deviation from the mean) levels of the pace of technological development and market heterogeneity, respectively. Figure 1 depicts the effect of technological radicalness on sales growth for varying degrees of pace of technological development.

Insert Figure 1 about here

We performed a simple slope analysis for each regression line to test whether its slope is significantly different from zero (Aiken & West, 1991). The tests revealed that both slopes are significantly different from zero. Start-ups exploiting radical technology therefore profit from higher levels of development pace in their technological environment whereas these types of firms suffer from low development paces. Contrary, start-ups exploiting less radical technologies seem to profit from a low development pace and underperform in environments with a high pace of technological development. Thus, Hypothesis 2 is supported.

Figure 2 shows the effect of technological radicalness on sales growth for varying degrees of market heterogeneity.

Insert Figure 2 about here

The slope for high levels of market heterogeneity proves to be significantly negative whereas the slope for low levels of market heterogeneity is not significantly different from

zero. Start-ups with more radical technologies therefore suffer from heterogeneous market conditions, but the performance impact of technological radicalness is neutral, when markets are homogeneous. Thus, results support Hypothesis 3.

5 Discussion

This study analyzes the effects of technology characteristics (i.e. technological radicalness) in start-up firms based on their commercialization success. While previous research argued that radical technologies are advantageous for exploitation through firm formation (Shane, 2001a), we analyzed the nexus between technology and commercialization outcome in start-up firms. Using a unique dataset that combines survey data from technology-based start-ups with assigned objective patent data from the PATSTAT database, our results reveal that the technological radicalness per se has no effect on the market performance of start-ups in terms of sales growth. Our study further examines the role of environmental conditions in the technological field (i.e. the pace of technological development), shaping the opportunities for market entry of start-up firms, and market characteristics (i.e. the market heterogeneity), resulting from the market entry decision of start-ups. We find empirical evidence for the fact that start-ups commercializing radical technological inventions find fruitful exploitative conditions if the pace of technological development in the technological field is high and the markets chosen for product entry are homogeneous. Our findings are in line with prior studies. Zahra (1996) showed for a sample of established manufacturing firms that in highly dynamic and moderately heterogeneous environments, these firms can profit from conducting more basic research and pursue pioneering technology strategies. Zahra and Bogner (2000) explained for a sample of U.S.-based software firms, that innovating and pioneering behavior contributes to a firm's success in dynamic industrial environments, but did not find the expected positive moderating effect of market heterogeneity.

Thus, this study contributes to overcome limitations in prior empirical research in the literature on entrepreneurship and technology management alike. Our findings expand previous insights into the role of technological characteristics for start-up firms' commercial success and enhance the understanding of how environmental conditions in the technological

field and markets influence this relationship. Possible limitations notwithstanding, the findings have major implications for theory, practice and policy.

5.1 Limitations and outlook

In interpreting the results of this study, certain limitations must be kept in mind. First, our analysis is based on start-ups from public research institutions. These inventions are on average more important and general than those in the private sector (Henderson et al., 1998). The generalization of our results is therefore limited by the representativeness of inventions from public research institutions.

Second, the sample consists solely of German start-ups, raising the question of the transferability of results to other national contexts. While this study is not internationally comparative in nature and therefore cannot offer any answers to this question, the theoretical considerations presented in this article are not country-specific. Nevertheless, future studies are encouraged in order to examine these issues in different national contexts such as North America or Asia.

Third, while sales growth assesses the market acceptance of a start-ups' commercialized technology, it does not provide any indication regarding the profitability of the firms. Further indicators for commercial success like profit or return on investment would be desirable. However, such information is difficult to obtain and difficult to compare across firms since time to break-even varies greatly across different industries and business models. Moreover, we cannot rule out that an underperforming firm in our sample could become an outperformer in the long run. However, we have no reason to believe that this will systematically be the case.

Finally, we employed patent data to assess the technological radicalness of inventions. Our study is consequently limited to start-ups and founding teams which have applied for at least one patent during the firm formation period. Moreover, one may question the construct validity of our patent based measure for technological radicalness. While many other studies employed this measure (Nerkar & Shane, 2003; Rosenkopf & Nerkar, 2001; Shane, 2001a) we must caution readers to interpret the results of our study with respect of the measure validity of technological radicalness.

5.2 Theoretical implications

First, our effort provides empirical evidence that the radicalness of technological inventions, which theory suggests should have a positive impact on the commercial success of start-up firms (Bond & Houston, 2003; Chandy & Tellis, 1998; Henderson & Clark, 1990), does not affect the performance outcomes of these firms per se.

Second, our study contributes to the understanding of how technological characteristics determine a different setting for firm formation. While previous academic literature has emphasized the importance of firm capabilities and team characteristics on commercialization success of start-up firms (Deeds, DeCarolis, & Coombs, 2000; Song et al., 2008), the importance of technological characteristics shaping exploitation opportunities has often been overlooked. As Nerkar and Shane (2007) have shown, the likelihood of technology commercialization is dependent on technological characteristics (patent scope, pioneering nature, and age of invention). We enhance these findings by considering the dimension of technological radicalness and taking commercialization outcome into account.

Third, our results provide useful insights for technological life-cycle theory. Scholars have argued that technological change is significantly driven by academic research and start-up firms are the central mechanism to bring these new technologies to market (Jaffe, 1989; Walsh, 1984). However, many of these firms exit the markets without generating substantial economic value (Gort & Klepper, 1982; Lockett & Wright, 2005; Sood & Tellis, 2005). Future research can enhance our understanding of start-up firms as drivers of technological change by considering the characteristics of these firm's technological assets.

Finally, our results connect to entrepreneurship literature and provide new insights on the effects of market entry choice in technology-based start-ups. As Gruber et al. (2008) have shown, having a broader choice-set of market opportunity is beneficial for start-up firms. Entering heterogeneous markets with distinct customer demands and market conditions however is only beneficial if the technology exploited has a low degree of radicalness. For highly radical inventions, start-ups should first enter more homogeneous markets for technology commercialization.

5.3 Managerial and policy implications

This study offers several implications for the management of new technology-based ventures and technology exploitation policy. The findings reveal that founders of start-ups can enhance the performance of their ventures by carefully analyzing the characteristics of their technology and possible entrance markets. While start-ups based on less radical technologies benefit from entering heterogeneous markets and serving simultaneously distinct customer needs, start-ups exploiting radical technologies should consider more homogeneous markets with clear-cut customer demands and market characteristics for market entry.

Further, public research institutions are interested in enhancing their technology transfer policies since they generate revenues from the commercialization of their technologies. Our study clearly shows that the public research institutions should not only pay attention to technological characteristics when choosing an adequate mechanism for technology transfer (Shane, 2001a), but should also take into account the pace of technological development for the specific technological fields. When the pace of technological development is low, start-ups' commercialization outcomes for radical technologies are considerably worse than in fast changing technological fields. Therefore, under these conditions, technology transfer offices should think about alternative commercialization instruments such as selling or licensing the technology to established firms.

Taken together, these implications highlight that the success of start-ups does not solely depend on technological characteristics in their commercialization efforts. Conditions of their specific technological environment as well as market conditions play a crucial role for commercialization outcome. Moreover, these factors are relevant across the technological fields of firms as well as for firms of different age and size.

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Table 1: Descriptive Statistics and Correlations

Variable	MW	SD	1	2	3	4	5	6	7	8	9	10	11	12
1. Sales Growth ^d	0,42	0,37	-											
2. Biotechnology ^a	0,31	0,46	-0,08	-										
3. Software/simulation ^a	0,14	0,35	-0,01	-0,27 *	-									
4. Electronics ^a	0,29	0,46	-0,08	-0,43 ***	-0,26 *	-								
5. Nanotechnology/new materials ^a	0,18	0,38	0,21 *	-0,31 **	-0,19 ^t	-0,30 **	-							
6. Patent portfolio	5,40	7,20	-0,18 ^t	0,25 **	-0,27 **	-0,07	0,04	-						
7. Spin-off age	5,51	1,92	-0,44 ***	0,18 ^t	-0,09	0,14	-0,34 ***	0,24 *	-					
8. Spin-off size	11,49	17,53	-0,08	0,17 ^t	-0,12	0,13	-0,20 *	0,37 ***	0,42 ***	-				
9. Start-up experience ^{a b}	0,39	0,49	0,06	-0,06	0,09	-0,04	0,14	0,01	0,03	-0,04	-			
10. Venture capital ^{a c}	0,19	0,39	0,10	0,20 ^t	-0,20 ^t	0,09	-0,07	0,22 *	0,03	0,30 **	-0,01	-		
11. Technological radicalness ^d	0,87	0,60	-0,04	0,06	-0,13	0,06	0,03	0,10	0,12	0,11	-0,16 ^t	0,11	-	
12. Pace of technological development	3,57	1,36	0,07	0,17 ^t	0,03	0,05	-0,18 ^t	0,04	0,12	0,24 *	-0,11	0,09	0,15	-
13. Market heterogeneity	4,30	1,68	0,08	-0,17 ^t	0,04	0,06	0,13	0,16	0,04	0,17	0,05	0,01	-0,16	0,05

n = 85; ^a Dummy Variables; ^b 1 = start-up experience by at least one founder, 0 = else; ^c 1 = at least one venture capitalist holds stake in firm equity, 0 = else

^d Ln-transformed; *** p ≤ 0,001; ** p ≤ 0,01; * p ≤ 0,05; ^t p ≤ 0,1 (two-tailed tests).

Table 2: Regression Results

	Sales Growth					
	Model 1		Model 2		Model 3	
	β	St.E.	β	St.E.	β	St.E.
Constant	0,43 ***	0,13	0,48 ***	0,14	0,39 ***	0,13
<i>Controls</i>						
Biotechnology	-0,07	0,15	-0,11	0,15	-0,03	0,15
Software/simulation	-0,10	0,16	-0,16	0,17	-0,14	0,16
Electronics	-0,03	0,15	-0,08	0,15	0,01	0,14
Nanotechnology/new materials	0,05	0,16	0,02	0,17	0,06	0,16
Patent portfolio	-0,01	0,01	-0,01	0,01	-0,01	0,01
Spin-off age	-0,08 **	0,02	-0,08 **	0,02	-0,08 ***	0,02
Spin-off size	0,00	0,00	0,00	0,00	0,00	0,00
Start-up experience	0,08	0,08	0,07	0,08	-0,01	0,08
Venture capital	0,11 ^t	0,11	0,19 ^t	0,11	0,15	0,10
<i>Main effects</i>						
Technological radicalness			0,00	0,07	-0,03	0,06
Pace of technological development			0,04	0,03	0,03	0,03
Market heterogeneity			0,02	0,02	0,02	0,02
<i>Interaction effects</i>						
Technological radicalness X Pace of technological development					0,13 **	0,05
Technological radicalness X Market heterogeneity					-0,07 *	0,04
R ² (adjusted R ²)	.27 (.18)		.30 (.18)		.39 (.27)	
ΔR^2	.27 **		.03		.09 **	
F	3.086 **		2.506 **		3.218 **	

n = 85; non-standardized coefficients, Coding: 1 = start-up experience by at least one founder, 0 = else; c 1 = at least one venture capitalist holds stake in firm equity, 0 = else; ^t p ≤ 0,1, * p ≤ 0,05, ** p ≤ 0,01, *** p ≤ 0,001 (two-tailed tests).

Figure 1: Interaction effect of technological radicalness and pace of technological development

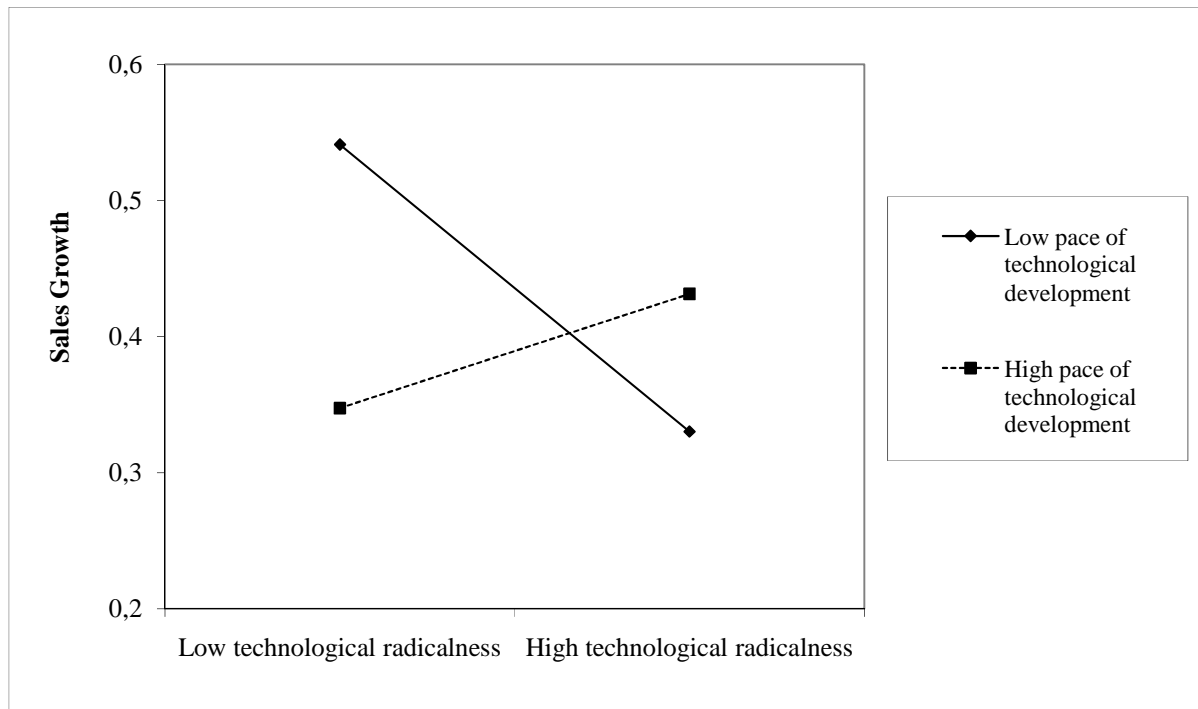
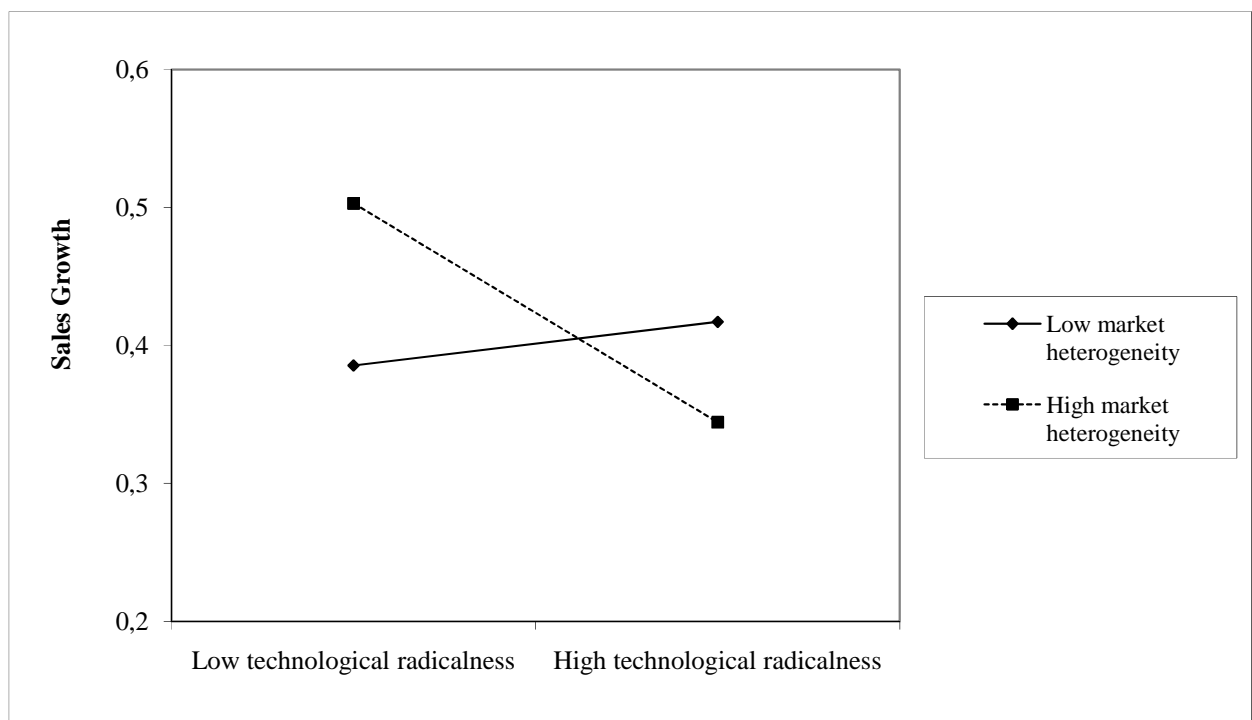


Figure 2: Interaction effect of technological radicalness and market heterogeneity



Appendix A

$Sales_{t_0}$ = latest business period; $Sales_{t-1}$ = one year ago; $Sales_{t-2}$ = two years ago

$$Sales\ growth = \ln \left[\left(Sales_{t-1} / Sales_{t-2} * Sales_{t_0} / Sales_{t-1} \right)^{1/2} \right]$$

	Factor loading	t-value
Pace of technological development ($\alpha = 0.82$, CR = 0.81, AVE = 0.48)		
(1) Many companies conducted research within my company's technology field.	0.63	6.02
(2) The number of companies conducting their own R&D in my company's technology field was growing rapidly.	0.77	7.83
(3) Many groups of researchers in public research institutions were active in my company's technology field.	0.82	8.54
(4) The number of groups of researchers in public institutions conducting research in my company's technology field was growing rapidly.	0.82	8.48
(5) The time between important technological breakthroughs in the technology field was decreasing quickly.	0.30	2.64
Market heterogeneity ($\alpha = 0.85$, CR = 0.84, AVE = 0.64)		
Are there large differences among your products / services regarding...		
(1) ...customer buying habits?	0.74	7.35
(2) ...the nature of competition?	0.86	8.78
(3) ...market dynamics and uncertainty?	0.80	8.01

Parameter estimates are standardized, α = Cronbach's alpha; CR = Composite reliability; AVE = Average variance extracted; $\chi^2/df = 2.06$; GFI = 0.9; AGFI = 0.81