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Abstract

Similar to the creation and distribution of new knowledge through industrial R&D and university research, entrepreneurial activity tends to vary across regions. Therefore the regionalized production of new knowledge is a prerequisite of entrepreneurial innovation. Based on endogenous growth theory, in particular the so-called Griliches-Jaffe-Model of regional knowledge production, we investigate industrial and university characteristics as determinants of technologically oriented entrepreneurship. Using hand-collected data from multiple sources, our results clearly show that high technology entrepreneurship is highly dependent on regional knowledge production by industry *and* university, while medium technology entrepreneurship does largely not dependent on these factors.

Regional Variations of High-Technology Entrepreneurship

Since entrepreneurial innovation has been identified as the driving force of economic growth (Audretsch, Keilbach, & Lehmann, 2006, p. 4; Schumpeter, 1964), both scholars and politicians have focused their attention on various aspects of the processes of entrepreneurship and its effects on the economy (Acs & Storey, 2004). Economists like Storey (1991) and Reynolds, Storey and Westhead (1994) have observed that entrepreneurship is not a random event. In particular they indicate that entrepreneurial activities tend to vary systematically across regions. Spatial differences in firm birth rates can be traced back to differences in regions' endowment with factors influencing new venture creation (Armington & Acs, 2002; Sutaria & Hicks, 2004; Taylor, 2002). Knowledge is one of these region-specific factors for which scholars have found evidence that more entrepreneurial opportunities are provided in regions which are rich in knowledge (Audretsch, Dohse, & Niebuhr, 2009; Audretsch & Keilbach, 2007; Audretsch et al., 2006). The increasing prominence of the factor knowledge is also apparent by the shift in economic activity away from traditional towards high technology industries in developed countries such as the U.S. and Germany.

As predicted by the endogenous growth theory, the key factors influencing regional entrepreneurship are the creation and distribution of new knowledge via relatively immobile human capital (Arrow, 1962; Romer, 1986, 1990; Uzawa, 1965). Therefore the regionalized production of new knowledge is a prerequisite of entrepreneurial innovation and has been formalized by Griliches (1979) and extended by Jaffe (1989). This 'regional knowledge production function', also known as Griliches-Jaffe-Model, predicts economically relevant knowledge as a combination of industry R&D and university research.

Current research on regional differences on new firm formation, which investigates the determinants of variations in new firm birth in regions, significantly contributes to a better understanding of entrepreneurial activities and its possibilities of political promotion in the regional context (Audretsch et al., 2009; Fritsch & Mueller, 2007; Hart & Gudgin, 1994; Lee, Florida, & Acs, 2004; Reynolds, 1994; Sutaria & Hicks, 2004). However, there are some major shortfalls. First, based on the assumption that entrepreneurship is homogenous, different technology levels of entrepreneurship have not been taken into account. Investigations of motivational backgrounds of entrepreneurial activities, though, have discovered significant differences regarding entrepreneurs' motivations to start a company. Thus the distinction between so-called "necessity" and "opportunity" entrepreneurship has been made (Acs, 2006; Audretsch et al., 2006, pp. 34). In this context, one might wonder why the distinction between different levels of knowledge, in connection with entrepreneurship, has been ignored so far. Second, the existing literature primarily focuses on the influence of the determinants of industrial knowledge production, neglecting the influence of university research, whereas the literature on academic entrepreneurship (e.g. university spin-off, patenting and licensing and contract research) suggests such investigations (for a detailed overview see Rothaermel, Agung, & Jiang, 2007).

In this paper, we overcome these drawbacks by taking both industry and university characteristics as determinants of spatial variations in entrepreneurship into account. Moreover, we not only show that it is important to distinguish between high technology entrepreneurship and technology driven entrepreneurship, our empirical results also suggest, that factors influencing regional variations in new firm formation differ with respect to the technology level of the new venture. In addition, we show that the research intensity and technology transfer orientation of universities predict the occurrence of high technology start-ups. Finally, the results of this investigation imply that basic research and technology transfer efforts of universities are essential in the process of high technology firm formation and therefore deserve special attention by scholars, policy makers and university officials.

The remainder of the paper is organized as follows. The subsequent section presents the theoretical background on regional knowledge production. Section three discusses key research on spatial variation in new firm formation, followed by an outline of university characteristics and spillovers in section four. In the fifth section a detailed description of the data set and a discussion of the variables used in the investigation are provided. Section six presents and discusses the results of the econometric analysis and concludes.

Endogenous Growth and Knowledge Production

This paper builds largely on three distinct areas of research: knowledge production, regional variations in (high-technology) entrepreneurship, and universities as sources of knowledge spillovers. Apparent from the previous discussion, it is the factor knowledge, which builds the link between these three strands of literature. For this reason, special attention is given to the theoretical background of knowledge as a factor influencing economic growth, and in particular to the production of knowledge. In the Solow (1956) model of economic growth, based on the neoclassical production function, economic growth is a function of physical capital and labor on a certain technological level. Although Solow (1957) finds evidence for a latent variable, it is Romer (1986) who manifests this variable as new knowledge embedded in human capital in his model of endogenous growth. New knowledge is thereby created in an interactive learning process where innovation (Arrow, 1962) and education (Uzawa, 1965) play a crucial role. In his model of endogenous growth Romer (1986, 1990) differentiates between university R&D, industrial R&D and industrial innovation in the production process: universities produce new knowledge using human capital in form of research and education, industry creates innovation, i.e. new technologies, using research findings and human capital, and industrial production creates goods applying these technologies. Romer’s clear threepart distinction (Romer, 1990), however, becomes increasingly unsustainable as universities engage more and more in technology transfer, which makes it difficult to assign innovative output to either industry or university efforts. In the model of the knowledge production function (Griliches, 1979; Jaffe, 1989), though, this difficulty of entangling industry and university characteristics leading to innovation has been solved. The regional knowledge production function describes innovation as the result of purposeful industry-specific and university-specific investments in knowledge inputs. That is, the Griliches-Jaffe-Model predicts economically relevant knowledge as a combination of industry R&D and university research (Griliches, 1979; Jaffe, 1989).

Knowledge, in particular economically useful new knowledge and knowledge spillovers leading to innovation, play not only a vital role in economic growth, but also in regional economic and social development (Acs, Anselin, & Varga, 2002). This Griliches-Jaffe-Model (Griliches, 1979; Jaffe, 1989) and its variations, i.e. modifications and extensions, have been widely used to explain regional differences in the production of new knowledge.[1] The remainder of this section discusses the knowledge production and the role of knowledge in the spatial context.

Knowledge spillovers play a key role in the literature of knowledge creation, whereas Jaffe (1989) is “the first to identify the extent to which university research spills over into the generation of inventions and innovation by private firms” (Acs, Audretsch, & Feldman, 1992, p. 363). By modifying the knowledge production function, Jaffe (1989) illustrates the combined effect of university and industry research and development in the generation of new economically useful knowledge, while confirming the importance of the spatial context in terms of knowledge spillovers.

[1] A comprehensive review of current approaches can be found in Drucker and Goldstein Drucker, J., & Goldstein, H. 2007. Assessing the Regional Economic Development Impacts of Universities: A Review of Current Approaches. ***International Regional Science Review***, 30(1): 20-46..

Jaffe, Trajtenberg and Henderson (1993) investigate knowledge spillovers by looking at the process of patent citation. They match the geographic location and the industry affiliation of the cited patent with those of the citing patent. In addition, Jaffe, Trajtenberg and Henderson (1993) differentiate between university and industry patents. They find evidence for significant localization effects; more precisely, they show that most patent citations occur in the respective region of the original patent. Thus, there is a clear pattern of localization at the country, state and regional level for the observed citation of patents. Even though innovations spatially spread more and more over time, this delocalization effect remains rather small overall. The same patterns occur for universities and firms, as both receive relatively similar domestic citation rates, after excluding self-citations. Moreover, the results of Jaffe, Trajtenberg and Henderson (1993) indicate that there is no concentration of patent citations within the same industry or technology class. In particular, almost half of all patent citations do not take place within the same primary patent class, and about a quarter of the citations can be traced back to completely different technological classes and industries. Thus, they were able to show that knowledge spillovers are on the one hand spatially restrained, but on the other hand are not restricted to the same industry and technology class respectively. Last finding points to the importance of industry diversity in a region.

Further evidence of the importance of geographic proximity in the process of knowledge spillovers is provided by Varga (2000). By adopting the Griliches-Jaffe knowledge production function (Griliches, 1979; Jaffe, 1989), he is able to show that the concentration of economic activity in cities has a positive effect on regional university knowledge spillovers. Thus, Varga (2000) contributes to the literature of knowledge spillovers, in particular university spillovers in the context of industry concentration and industry diversity, i.e. Marshall-Spillovers versus Jacobs-Spillovers. Marshall-Spillovers occur between firms within the same industry through the exchange of human capital as well as imitation. The regional concentration of a specific industry produces economies of scale due to specialization effects, in particular the industry-specific pool of human capital. (Marshall, 1890; Romer, 1990) Jacobs-Spillovers, however, are fostered by industry diversity. Knowledge spillovers occur between firms of different industries, which operate in the same regional market, thereby promoting innovation and productivity (Jacobs, 1969).

To summarize the above discussion, knowledge production as a function of combined industry and university R&D expenditures and knowledge spillover are both object to geographic proximity. Therefore the investigation of the production and spillover mechanism of knowledge requires not only the inclusion of industry and university at the same time, but also the regional context, which plays a crucial role in the analysis.

Regional Characteristics and Variations in Entrepreneurship

Linking regional variations in entrepreneurship to region-specific characteristics is certainly not new. Looking back at the early attempts of examining spatial differences in entrepreneurial firms, the focus of these studies was to highlight and to quantify regional differences in start-up rates (Lloyd & Mason, 1984; O'Farrell & Crouchley, 1984). Nonetheless, some researchers have already paid attention to new high-technology firms at that time.

In their study, Gould and Keeble (1984) examine trends in new venture creation in the manufacturing industry for twenty local authority districts of East Anglia, U.K., over time. In addition, an investigation of the regional bias towards rural areas and the progressive Cambridge region, and an analysis of the geography, character and impact of high technology start-ups have been conducted. Their empirical results suggest that regional differences in firm birth can be traced back to variations in the occupational structure of the regional workforce. The mix of the local workforce, i.e. the proportion of the population with managerial, professional, technical or other non-manual qualifications, measures the pool of potential entrepreneurs. Moreover, a key determinant of spatial variations is the industrial concentration, whereas the industrial composition of new firms reflects the existing mix of industries. This captures the stimulating spillover effects between firms within the same industry (Arrow, 1962; Marshall, 1890; Romer, 1990).

According to Gould and Keeble (1984), the size of plants and industrial in-migration seem to play a minor role. The regional size-structure of firms captures a regions' dependency on employment in large enterprises, which tend to restrain entrepreneurial activities. The move of mostly small and medium-sized firms into the analyzed area, like the regional occupational structure, measures the pool of potential entrepreneurs. Although Gould and Keeble (1984) are only able to attribute insignificant effects in terms of regional economic contribution to new high-technology firms, they find a striking spatial clustering of such start-ups in the area around the University of Cambridge. This can be seen as an early hint to the relevance of research intensive universities for high technology start-ups.

A decade later, Keeble and Walker (1994) investigate the key factors which explain spatial variations in new firm formation, the growth in number of small firms as well as firm death rates for different sectors in all 64 UK counties during the 1980s in more depth. Econometric analysis reveals that the most important and positive influences on new firm formation are previous growth of the regional population and the availability of capital. While latter supply-side variable is measured by housing prices, the population growth, which describes the average annual percentile change in total population, captures supply- as well as demand-side influences on entrepreneurship. A professional and managerial occupational structure and structural mixture in terms of firm size also have a positive impact on entrepreneurial activity. As in Gould and Keeble (1984), the occupational as well as firm size mix describe the pool of potential entrepreneurs. They also point out that the determinants of spatial variation in new firm birth slightly differ with respect to different sectors – production, service and the total economy (Keeble & Walker, 1994).

A more recent study by Armington and Acs (2002) finds significant differences in new firm birth rates across U.S. labor market regions. The regression results show differences regarding the effects of regional characteristics on new venture creation when distinguishing between six industrial sectors. According to Armington and Acs (2002) spatial differences in industry intensity, population growth, income growth, and in particular human capital – all showing a positive impact – considerably contribute to the explanation of regional variations in start-up rates. Industry intensity and population growth were thereby included to control for effects of regional spillovers, while human capital captured by two levels of educational attainment (no high-school vs. college degree) which describe the existing pool of potential entrepreneurs. Moreover, Armington and Acs (2002) argue that significant differences in new firm formation rates from industrial to technologically progressive areas exist. However, they do not explicitly test for it. Hence, regional factors that actually foster high technology entrepreneurship are not explored by Armington and Acs (2002). The correlation coefficient between technology start-ups and high-technology start-ups is 0.13. This underlines the necessity of a deeper investigation of the different types of entrepreneurial activity with respect to technology levels.

In the most recent and more sophisticated study on regional variations in entrepreneurial activity, Audretsch, Dohse and Niebuhr (2009) go a step further. In their investigation they do not only analyze the effect of the regional environment as well as knowledge and cultural diversity on the entrepreneurial activity for German labor market regions, they also examine if different forms of entrepreneurship, that is, start-ups with different technology levels, are influenced by different regional determinants. Audretsch, Dohse and Niebuhr (2009) succeed to show that the factors having an impact on new venture creation differ significantly with respect to the technology level. Their results also show that regions rich in knowledge, measured by R&D employment and high human capital, are much better breeding grounds for entrepreneurial activities than other regions. Moreover, spatial diversity, in form of sectoral and cultural diversity, are key influences on entrepreneurship, whereas sectoral diversity tends to have a negative impact on the firm birth rate, in contrast to cultural diversity which has a significantly positive impact on start-up activity.

While a variety of major region-specific factors has been linked to regional entrepreneurial activity in these studies, further determinants have been identified to have an influence on new firm birth. Davidsson, Lindmark and Olofsson (1994), Fritsch and Mueller (2007), Brixy and Grotz (2006), as well as Audretsch et al. (2009) have found urbanization effects, measured by population density, to have a positive impact on the rate of start-ups. Human capital in form of college graduates haves also been identified to have a positive impact on new firm birth after all (Armington & Acs, 2002; Guesnier, 1994; Lee et al., 2004).

University Characteristics, Spillover Effects and Entrepreneurship

The relatively new field of university entrepreneurship is a scholarly area of interest that experienced increasing attention within the last ten years. Correspondingly, there is a growing body of literature on academic entrepreneurship research. Comprehensive reviews of the literature can be found in Phan & Siegel (2006), who summarize more than 50 empirical studies concerning university-to-industry-technology-transfer (UITT), and Rothaermel, Agung & Jiang (2007), who review more than 120 papers in their recent taxonomy of UITT literature. In this section, we do not fully cover all aspects of academic entrepreneurship; instead, we focus on central characteristics of universities which are prerequisite for knowledge spillovers fostering high technology entrepreneurship. Universities can be characterized as firms with several knowledge products, which are offered to different target groups (Warning, 2007). These knowledge products are: research, teaching, and technology transfer (Etzkowitz, 2003).

The production of new knowledge through *research*, as the main business of universities (McDowell, 2001), is of crucial importance for economic and social development. Research results are included in future research; teaching as well as technology transfer is based on research results, which are economically used in form of new technologies. Generally speaking, universities conduct more basic research than firms, as they are not forced to use the research results immediately (Warning, 2007). Firms, on the contrary, generally focus on applied research. Various measures to determine university research exist. Measures of research performance indicators like the number of publications or the number of citations – only to mention a few – are commonly accepted and widely used (Agrawal & Henderson, 2002; Azoulay, Ding, & Stuart, 2007; Dusansky & Vernon, 1998; Lach & Schankerman, 2003).

Teaching is closely related to the research activities of a university and shows the social, directly visible output of these academic institutions (Chesbrough, 2003). While research results are initially used in a relative small scholarly community, knowledge, which has been imparted through teaching, is spread throughout the society and is economically utilized in value-adding processes. The role of academic teaching is twofold: imparting knowledge to undergraduate and graduate students on the one hand, and to doctoral students on the other hand. While the goal of (under)graduate education is to directly, economically utilize the newly acquired knowledge, postgraduate education in turn enhances knowledge production. Graduated doctoral students either become researchers at universities or in the industry, or they increase the absorbing capacity of new knowledge in the industry. (Cohn & Cooper, 2004) Thus, teaching contributes to the production of new knowledge in the form of human capital. Measures to determine university teaching in terms of human capital generation are, amongst others, the absolute number of (under)graduate students and doctoral students. However, human capital is not only a key output of university teaching, it is also a key resource of university research, which illustrates the complementarities of the co-products research and teaching (Neumann, 1992).

As a by-product of research and teaching, *technology transfer* is an additional output of universities, which Etzkowitz (2003) also describes as the third mission of a university. New knowledge, produced through research activities of universities, is on the one hand one of the most codified forms of knowledge in form of publications or patents, on the other hand this new knowledge is also highly idiosyncratic. However, the codified part of knowledge by itself is not of much value. The implicit part of academic knowledge, which is tied to specific institutions and scholars, is crucial in order to economically utilize this new knowledge (Collins, 1992, pp. 22). These conditions make an active exchange between universities and industry, in order to use research results for product development, inevitable. Due to this crucial interaction, i.e. the nature of knowledge spillovers, the demand for university-to-industry-technology-transfer (UITT) is geographically limited and varies among industries (Jaffe, 1989).

The supply of UITT is a function of past university-industry exchange and learning. Relevant knowledge about the ability to patent certain types of technologies and innovations, patenting processes, marketing as well as licenses is accumulated by universities over time. This kind of path dependency is essential as the administration and policies of universities tend to evolve gradually. According to Phan and Siegel (2006) early experience with technology transfer fosters future technology transfer. The integration of universities in a spatial innovative milieu might have positive effects on technology transfer in terms of the extent as well as the timing of technology transfer. Furthermore, a university's embeddedness might also support the accumulation of human and financial capital within the research institution.

A crucial factor enabling research activities – and therefore technology transfer – is third party funding. Normally, research budgets of public universities are rather small. Academic knowledge creation and knowledge transfer therefore require additional research funding by third parties such as industrial or national institution. Even though industry is more and more interested in supporting basic research, national research agencies or scientific foundations are still amongst the major providers of research funding. Just as companies, these research sponsors also increasingly pay attention to their expenditures and the expected monetary value in terms of transferable knowledge (EC, 2008).

In summary, to capture all relevant and crucial aspects of universities it is important to look at universities as a whole. This especially involves all three kinds of university outputs, which are research, teaching and technology transfer.

Sample

To test the influence of university and industry characteristics on high technology entrepreneurship, we use a unique and hand collected dataset. The geographic unit of analysis used for this investigation are functional districts, so-called Labor Market Areas (LMAs) or travel-to-work areas (Eckey, Kosfeld, & Türck, 2006). LMAs are economically integrated geographic regions which make it possible to control for regional knowledge spillovers through human capital mobility. In order to measure the impact of both, industry and university characteristics on new high-technology firm formation, only those LMAs are included in the investigation in which universities are located. Therefore the cross section consists of 56 LMAs.

To analyze the combined effects of industry and university characteristics on high technology entrepreneurship in the 56 German travel-to work areas, this study uses measures of start-up intensities, which are calculated as the actual start-up rate per 10,000 inhabitants, that is the population of working age. Due to the high annual variations in venture creation rates of innovative firms, a four-year average (2004-2007) of firm birth rates is used for the regression analysis. In this investigation we focus on two different groups of new firm formation of the Mannheim Enterprise Panel (Metzger & Höwer, 2009): technology start-ups and high technology start-ups. Technology start-ups are thereby companies producing printers, lightning products, motor vehicles, etc., whereas high-technology start-ups operate for instance in the pharmaceutical, weaponry or aerospace industry. Detailed information about the data set and the classification of start-ups in terms of their technology levels is provided by Metzger and Höwer (2009). As indicated by the correlation coefficient of 0.13 between high technology and technology start-ups in Table 2, there are significant variations in the firm birth rates at the two technology levels within the analyzed labor market areas. This suggests that high technology firm formation and technology firm formation might be determined by different factors of influence (Audretsch et al., 2009).

The dataset of new firm formation has been combined with a unique and hand collected dataset of indicators of industry and university characteristics within each of the 56 observed regions. All variables and the descriptive statistics are displayed in Table 1.

One of the four industry variables, which are included in the analysis, is the output oriented indicator of innovation, measured by the number of industry patents per year (Industry Patents). Marshall-Spillovers are captured by the variable industry concentration measured as gini coefficient in terms of employment (Industry Concentration), while industry diversity, measured by the number of different industries, controls for Jacobs-Spillover (Industry Diversity) (see Jaffe et al., 1993). The interaction term of industry concentration and diversity, simply constructed as a multiplier of these two variables (Industry Concentration*Industry Diversity), is included to possibly give some insights on the dominance of one of these two spillover effects.

--- *insert table 1 about here* ---

University variables, which are also modeled as output-oriented measures, can be categorized according to the three knowledge products offered by universities. The number of publications (# Publication per Researcher/ Year) is a measure for research quantity, while the quality of research conducted at academic institutions is measured by the number of citations (# Citation per Researcher/ Year). University teaching is presented by measures of academic human capital formation: Whereas general human capital is captured by the number of students (# Students), high and specific human capital is modeled as the sum of doctoral students of one professor (# PhD Students per Professor/ Year). Besides, the number of students also controls for the size of a university. To take technology transfer at universities into account, two variables are modeled to capture different aspects of this factor. The variable third party funding (Third Party Funding per Year in 1000 Euro) includes both, contract research in form of industry funds as well as research grants by public research funds. The sum of both factors is to be interpreted as the result of past effective technology transfer, which in turn promotes future technology transfer (Phan & Siegel, 2006). The cumulative patent rate (# of all University Patents/age of first patent) describes active technology transfer by the university while at the same time controlling for learning effects (Arrow, 1962). Given the differences among industries in terms of knowledge spillovers, it is moreover controlled for the existence of a physics as well as bio-chemical departments (Physics Department; Biology/ Chemistry Department). All variables of industry and university characteristics alike are constructed as a four-year average (2004-2007) due to the construction of the dependent variable of firm birth rates.

The correlation matrix of firm birth rates at different technology levels and regional and university characteristics is given in Table 2. The dependent variables are not correlated. The number of publications is highly correlated with the number of citations and there is a moderate to strong correlation between high human capital and the number of publications as well as citations.

--- *insert table 2 about here* ---

Empirical Analysis

The empirical results of our OLS-regressions with robust standard errors are presented in Table 4. Two different models are presented to show the effects of regional and university characteristics on high technology and technology firm birth rates in 56 German LMAs. These two specifications differ in terms of the factor university patents, which is excluded in Model I (column 2 and 3), to control for the relatively new field of technology transfer. Most striking is the result that start-up rates at different technology levels are indeed explained by different factors of influence. The results of both models are congruent with findings of Audretsch, Dohse and Niebuhr (2009) that factors influencing spatial firm birth rates differ systematically with respect to different technology levels – albeit it is controlled for university knowledge spillovers. Moreover our results clearly show that university knowledge spillovers are not relevant for the most common forms of technology oriented entrepreneurship. However, they have a positive and highly significant impact on high-technology firm formation.

In both models, only Jacobs-spillovers (Jacobs, 1969), reflected by industry diversity, have a positive and highly significant impact on technology entrepreneurship. All other variables included in the models are not able to explain the regional formation rate of new technology firms. As can be seen from Table 3, the high technology firm formation rates are significantly higher in East Germany. This is the result of subsidies from the European Union as well as the German government for East Germany, which are granted for the reconstruction and development of the Eastern part of Germany since the German reunification. A good example is the prosperous region of Jena with its physics, optical and medical engineering cluster. The number of industry patents has a significantly positive impact on new high technology firm birth. This result is in line with the Knowledge Spillover Theory of Entrepreneurship (Audretsch & Keilbach, 2007). High technology start-ups choose to locate in highly innovative regions, as these firms expect to benefit from knowledge spillovers, whereas both forms of knowledge spillovers, Marshall- as well as Jacobs-Spillovers, reflected by industry concentration and industry diversity, are significantly important in the process of new high technology firm formation.

--- *insert table 3 about here* ---

However, only regions which are characterized by either industrial concentration or industrial diversity may show high rates of new high technology firm birth. That is, regions with a clear profile of either concentration or diversity, may profit from new start-ups in the high technology industry, as apparent from the negative and significant impact of the interaction variable of industry concentration and industry diversity. As predicted by the theory of the regional knowledge production function (Griliches, 1979; Jaffe, 1989), besides industry characteristics, university characteristics do also have a impact on the regional formation rate of high technology firms. Human capital, reflected by students and doctoral students, has statistically significant influence. While PhD students play a more important role in process of high-technology firm formation, the coefficient of students is negative and its squared term is positive. Both terms are statistically significant for high technology firm birth, suggesting that a critical mass on students is required. In both models, the coefficient for biology/chemistry department of a university in a region is negative and highly significant. This result supports the fact that the chemical industry is a relatively mature industry with not many new firm formations (see Hall & Soskice, 2001). In contrast, the existence of a physics department has a positive and statistically significant impact on the rate of high technology firm formation. The coefficient of university patents in Model II is statistically significant for high technology firm birth. While university patents are negative, its squared term is positive, suggesting that a critical mass on university patents is required, i.e. a certain learning effects (Arrow, 1962) of universities in terms of patenting are necessary for UITT to be successful. In additional models further factors, i.e. population density, were controlled for, which turned out not to be significant, i.e. the indicators do not explain high-technology entrepreneurship.

In this paper we were able to shed some light on the combined influence of industry and university characteristics on the formation rate of new high technology firms in German Labor Market Areas. Our findings show that the regional knowledge production framework only explains high-technology start-ups, but not technology entrepreneurship as a whole. Besides industry, universities, as sources of new knowledge, also play a crucial role in the process of high technology firm birth.

The investigation presented in this paper is the first to analyze combined influence of industry and university on firm birth at different technology levels. Further research is needed to get a better and more differentiated understanding of regional knowledge production resulting in high technology firm formation. The separation of third party funds into industry and government funds might thereby be a first step to give some valuable insights.

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Table 1: Summary statistics

Variables	**Mean**	**Std. Dev.**	**Min**	**Max**
Dependent Variables				
Technology Start-Up Rate	0.295	0.071	0.120	0.430
High-Technology Start-Up Rate	0.144	0.063	0.030	0.340
Industry Variables				
Industry Patents	562.719	828.381	19.100	4630.687
Industry Concentration	0.574	0.104	0.320	0.835
Industry Diversity	13.125	3.913	3	20
Industry Concentration*Industry Diversity	8.295	6.216	2.088	50.112
East Germany	0.179	0.386	0	1
University Variables				
# Citation per Researcher/ Year	64.780	29.959	0	133.500
# Publication per Researcher/ Year	10.461	3.703	0	17.313
# PhD Students per Professor/ Year	1.500	0.693	0	2.977
Third Party Funding per Year in 1000 Euro	35241.680	33732.260	0	179447
University Patents per Year	3.971	3.501	0.333	19.350
Physics Department	0.929	0.260	0	1
Biology/ Chemistry Department	0.857	0.353	0	1
# Students	23575.300	19289.800	2717	108585

Table 2: Correlation of firm birth rates at different technology levels and regional and university characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) Technology Start-Up Rate	1.00											
(2) High-Technology Start-Up Rate	0.13	1.00										
(3) Industry Patents	0.20	0.38	1.00									
(4) Industry Concentration	0.00	0.23	0.31	1.00								
(5) Industry Diversity	0.35	0.08	0.13	-0.11	1.00							
(6) Industry Concentration*Industry Diversity	0.15	0.15	*0.74*	0.47	0.12	1.00						
(7) # Citation per Researcher/ Year	0.06	0.21	0.32	0.01	0.23	0.03	1.00					
(8) # Publication per Researcher/ Year	0.02	0.11	0.22	-0.01	0.18	0.06	**0.86**	1.00				
(9) # PhD Students per Professor/ Year	-0.04	0.15	0.34	0.08	0.03	0.07	*0.78*	*0.77*	1.00			
(10) Third Party Funding per Year in 1000 Euro	0.08	0.23	*0.72*	0.08	0.23	0.26	*0.54*	0.42	*0.60*	1.00		
(11) University Patents per Year	0.10	-0.08	0.21	-0.03	0.06	0.10	0.23	0.34	0.31	0.36	1.00	
(12) # Students	-0.03	-0.01	0.46	0.01	0.39	0.15	0.39	0.33	0.40	*0.79*	0.29	1.00

Correlation >0.5 in italics, >0.8 in bold font

Table 4: Estimates of effects of regional and university characteristics on firm birth rate of 56 LMAs

Independent Variable: Start-Up-Rate	*Model I*		*Model II*	
	Tech	*HighTech*	*Tech*	*HighTech*
Industry Patents	0.0000 (0.000)	**0.0001 **** **(0.000)**	0.0000 (0.000)	**0.0001 **** **(0.000)**
Industry Concentration	0.0042 (0.146)	**0.2905 ***** **(0.074)**	0.0150 (0.149)	**0.2928 ***** **(0.072)**
Industry Diversity	**0.0085 ***** **(0.003)**	**0.0058 ***** **(0.002)**	**0.0087 ***** **(0.003)**	**0.0057 ***** **(0.002)**
Industry Concentration * Industry Diversity	-0.0021 (0.002)	**-0.0063 **** **(0.003)**	-0.0020 (0.002)	**-0.0058 **** **(0.003)**
East Germany	0.0272 (0.035)	**0.0361 *** **(0.019)**	0.0208 (0.036)	**0.0359 *** **(0.021)**
# Citation per Researcher/ Year	0.0000 (0.001)	**0.0008 *** **(0.000)**	0.0001 (0.001)	0.0006 (0.000)
# Publication per Researcher/ Year	-0.0012 (0.006)	**-0.0057 *** **(0.003)**	-0.0026 (0.007)	**-0.0044 *** **(0.003)**
# PhD Students per Professor/ Year	-0.0046 (0.029)	**0.0346 *** **(0.019)**	0.0033 (0.029)	**0.0409 **** **(0.018)**
Third Party Funding per Year in 1000 Euro	0.0001 (0.000)	0.0001 (0.000)	0.0001 (0.000)	0.0001 (0.000)
University Patents per Year	---	---	-0.0061 (0.007)	**-0.0093 **** **(0.004)**
(University Patents per Year)^2	---	---	0.0005 (0.000)	**0.0005 *** **(0.000)**
Physics Department	0.0017 (0.061)	**0.0560 *** **(0.029)**	0.0120 (0.063)	**0.0611 **** **(0.029)**
Biology/ Chemistry Department	0.0185 (0.040)	**-0.0597 ***** **(0.018)**	0.0093 (0.043)	**-0.0718 ***** **(0.019)**
# Students	-0.0001 (0.000)	**-0.0001 ***** **(0.000)**	-0.0001 (0.000)	**-0.0001 ***** **(0.000)**
(# Students)^2	0.0001 (0.000)	**0.0001 **** **(0.000)**	0.0001 (0.000)	**0.0001 **** **(0.000)**
Constant	**0.2015 **** **(0.096)**	-0.0490 (0.054)	**0.2013 **** **(0.099)**	-0.0441 (0.054)

N=56, OLS-regression models with robust standard errors.***p<0.01; **p<0.05; * p<0.1