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Regional Public Research, Higher Education, and Innovative Start-ups—An Empirical Investigation¹

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June 2013

Abstract

Based on detailed information about the regional knowledge base, particularly about universities, we find that regional public research and education have a strong positive impact on new business formation in innovative industries but not in industries classified as non-innovative. Measures for the presence and size of public academic institutions have more of an effect on the formation of innovative new businesses than indicators that reflect the quality of these institutions. We find relatively weak evidence for interregional spillovers of these effects. Our results clearly demonstrate the importance of localized knowledge and, especially, of public research for the emergence of innovative new businesses.

Keywords: New business formation, innovative start-ups, universities, regional knowledge

JEL-classification: L26, L60, L80, O18, R12, R30

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1. Introduction

New businesses are an important source of economic growth (see Fritsch, 2013), especially those start-ups that pose a competitive threat to incumbent firms by introducing a significant innovation. The available data suggest that only a small fraction of all start-ups is of such quality and that their geographic distribution is highly uneven (Fritsch, 2011). According to the knowledge spillover theory of entrepreneurship (Acs, Audretsch, Braunerhjelm and Carlsson, 2009), highly innovative new businesses can be especially expected in regions with significant amounts of knowledge, private or public.

This paper analyzes the role played by regional knowledge, particularly academic knowledge, in the emergence of innovative start-ups in Germany. Our study makes several significant contributions to this field of study.² First, we include all start-ups in innovative and knowledge-intensive industries.³ Second, our data comprise much more detailed information about higher education institutes (HEIs), such as universities, which allows us to identify those parts and features of a region's academic knowledge base that are most relevant for innovative start-ups.⁴ Third, while nearly all the earlier studies are based on pure cross-sections, our analysis uses relatively long time series data that allow us to employ panel estimation techniques. Fourth, our data include more recent periods. Hence, given the changing nature of German universities, our results and conclusions are not only more up to date but also more relevant than the results of studies that investigate the start-ups of the early 1990s. Fifth, we include Eastern Germany, the part of the country that was under a socialist regime until 1989 and a region that is neglected in some of the earlier studies (Harhoff, 1999; Bade and Nerlinger, 2000).

² Earlier studies for Germany are Harhoff (1999), Bade and Nerlinger (2000), Audretsch and Lehmann (2005), Audretsch, Lehmann and Warning (2005), and Hülsbeck and Pickavé (2012).

³ Harhoff's (1999) analysis is limited to start-ups in electrical machinery and the mechanical engineering industry. Audretsch and Lehmann (2005) and Audretsch, Lehmann and Warning (2005) focus on 281 firms that made an initial public offering (IPO) in Germany between March 1997 and March 2002. Since these firms may have been set up considerably in advance of making an IPO, their founding date is only vaguely defined.

⁴ We also include information about the non-university research institutions in the region, which are neglected in Audretsch and Lehmann (2005), Audretsch, Lehmann and Warning (2005), and Hülsbeck and Pickavé (2012).

The following section (Section 2) highlights the theoretical relationship between the three cornerstones of our analysis—innovative start-ups, geography, and knowledge, beginning with a review of previous research on the spatial determinants of innovative new business formation. Section 3 discusses the data and provides an overview of the geographic distribution of innovative start-ups in Germany. Section 4 introduces the estimation approach; the results of the multivariate analysis are presented in Section 5. Section 6 concludes.

2. Innovative start-ups, knowledge, and geography

2.1 Theory: Innovative start-ups as knowledge spillovers

The knowledge spillover theory of entrepreneurship (Acs, Braunerhjelm, Audretsch and Carlsson, 2009) is based on the assumption that starting an innovative venture requires a combination of knowledge and entrepreneurial talent. Since a large part of the necessary knowledge resides in incumbent firms, universities, and non-university public research organizations, this approach regards innovative start-ups as a form of knowledge spillover, that is, the institutional knowledge spills over into the newly founded business. A key assumption of the theory is that the knowledge commercialized by the innovative start-up would not be exploited if left in the incumbent organization.⁵

In the process of entrepreneurial knowledge spillover, there are at least two reasons why the regional dimension, in terms of geographic proximity, should be relevant. First, new knowledge does not flow freely across space but tends to be regionally bound (Anselin, Varga and Acs, 1997; Asheim and Gertler, 2005; Boschma, 2005). Second, founders show a pronounced tendency to locate their firm in close spatial proximity to their former workplace or to the place where they reside (Figueiredo, Guimaraes and Woodward, 2002; Dahl and Sorenson, 2009). Hence, innovative entrepreneurship is a “regional event”

⁵ A main reason for the knowledge remaining unexploited by the incumbent organization is that the economic value of new knowledge is highly uncertain and the expected value of any new idea will vary across economic agents. Hence, if an employee in a firm assigns a much higher economic value to a new idea than does the firm’s management, the employee may be motivated to start an own business based on this knowledge. For the researcher, starting an own business is often the only way to have an idea realized. For a more detailed discussion of this point, see Audretsch, Keilbach and Lehmann (2006) and Acs, Braunerhjelm, Audretsch and Carlsson (2009).

(Feldman, 2001; Sternberg, 2009), meaning that the regional knowledge stock, the regional workforce, and the regional conditions for entrepreneurship are important influences in the emergence of innovative new businesses.

2.2 Empirical research

2.2.1 Determinants of regional new business formation

Although innovative start-ups may be a special breed, they are not a totally different species than other kinds of new businesses. Hence, some of the results from empirical research into the determinants of regional new business formation should apply to innovative start-ups. According to empirical studies on the regional factors that determine the emergence of new businesses, employment share in small firms, regional industry structure, qualification of the regional workforce, level of innovation activity, and population density play especially important roles (Fritsch and Falck, 2007; Reynolds, Storey and Westhead, 1994; Sternberg, 2009). Other factors that may be important are the presence of entrepreneurial role models, regional “mentalities” such as fear of failure (Wagner and Sternberg, 2004), and a regional “culture” of entrepreneurship (Fritsch and Wyrwich, 2014).

As people with a high level of formal education tend to have a relatively high propensity to become entrepreneurs (Parker, 2009), a large share of well-educated people in a regional population should be conducive to new business formation. This may be particularly true for innovative start-ups that require high levels of knowledge and human capital. Since innovation activity is a main source of knowledge and entrepreneurial opportunities, a high level of research and development (R&D) activity in a region should have a positive effect on the emergence of new firms, particularly for innovative start-ups. To the extent that founders of innovative firms worked in R&D before starting their venture, and due to the strong tendency to locate a new business close to the founder’s residence, there should be a pronounced correspondence between the spatial distribution of innovative start-ups and that of R&D activity. Because founders are likely to set up their business in the industry in which they previously worked, there should also be a positive relationship between the number of

regional employees in innovative industries and the number of innovative start-ups.

There are two reasons why the share of small and, especially, young business employment could be important to innovative activity. First, small-firm employees show an on average higher propensity to start their own business than do employees of larger firms.⁶ Second, a high share of small-firm employment in a region indicates a high share of industries with low minimum efficient size, which implies low barriers to entry. Accordingly, the high start-up rates found in regions with high shares of small-firm employment may be explained by the prevalence of industries with low minimum efficient size (Fritsch and Falck, 2007).

A number of studies find a significant effect of population density on the propensity of the regional workforce to become self-employed. However, since population density is a “catch-all” variable that is statistically closely related to a number of factors that may be favorable or unfavorable for new business formation (e.g., depth of input markets, intensity of local competition, presence of research institutions and knowledge), this variable is not useful for discovering the reasons behind such a density effect.

2.2.2 Previous work on the geographic distribution of innovative start-ups

Most empirical studies on innovative new businesses identify them by their affiliation with certain industries that are classified as being innovative. A well-known classification of industries based on innovativeness is that of the OECD (2005), which chiefly categorizes industries by their R&D intensity. The OECD classification deals only with manufacturing industries, but certain service-sector industries, the “knowledge-intensive services,” may also be regarded as being innovative since they also spend rather significant shares of their resources on

⁶ For a discussion of the possible reasons for this, see Elfenbein, Hamilton and Zenger (2010), Parker (2009), and Wagner (2004).

R&D.⁷ In the following, we view knowledge-intensive services as a sub-group of the innovative industries.

Innovative industries tend to be highly concentrated in space (Markusen, Hall and Glasmeier, 1986; Bade and Nerlinger, 2000; Storey and Tether, 1998). A number of previous analyses of the regional distribution of innovative start-ups in Germany have shown a high concentration in larger cities and agglomerations.⁸ Bade and Nerlinger (2000) as well as Harhoff (1999) compared the results of multivariate analyses for start-ups in innovative industries with models for new businesses in sectors that are not regarded as being particularly innovative. Both studies find that universities, non-university public research institutes as well as private sector R&D has a statistically significant positive effect only for start-ups in innovative industries, not for new businesses in industries that are not classified as being innovative. Harhoff (1999) also finds a significantly positive relationship between a high qualification of the regional workforce and the emergence of innovative new businesses. Audretsch and Lehmann (2005) and Audretsch, Lehmann and Warning (2005) showed that there is a significantly positive relationship between the number of start-ups in innovative manufacturing and the presence of a university in a region as well as the number of students.

When analyzing the determinants of the regional number of start-ups in high technology and technologically advanced manufacturing industries, Hülsbeck and Pickavé (2012) identify a positive effect of several variables that reflect the activities of universities. According to their results, the number of university patents and the number of Ph.D. students per professor seem to be conducive to new business formation in high-technology industries; other

⁷ Since many service firms do not have a standardized product program but provide customer-specific services, they are not innovative in the same sense as manufacturing firms. Hence, service industries that may be relevant for innovation are defined as such based on the knowledge intensity of their inputs. These knowledge-intensive service industries include, for example, “computer services,” “research and development in natural sciences and engineering,” and “business consultancy.” For definitions of these groups of industries, see Grupp and Legler (2000) and OECD (2005). For a review of different methods of identifying innovative businesses, see Fritsch (2011).

⁸ Audretsch and Lehmann (2005), Bade and Nerlinger (2000), Harhoff (1999), Hülsbeck and Pickavé (2011), Lasch, Robert and Le Roy (2013).

university-related variables, however, have unexpected and statistically significant negative signs.⁹

Baptista and Mendonça (2010) investigate the geographic distribution and determinants of start-ups in innovative industries in Portugal. According to their analysis, the number of students, as well as the number of university graduates, has a significantly positive effect on the number of regional start-ups in all innovative industries, whereas the overall education level of the regional workforce is statistically significant only for the start-ups in knowledge-intensive services. Another significantly positive influence was found for the number of firms in innovative industries per 1,000 inhabitants, which can be regarded as a measure of relevant private-sector knowledge. Distinguishing between students and graduates in different academic fields, Baptista and Mendonça (2010) identify a statistically significant effect for students and graduates in engineering. The number of students and graduates in social sciences has an effect only for new business in knowledge-intensive services, not for start-ups in innovative manufacturing.

In another analysis of Portuguese regions, Baptista, Lima and Mendonça (2011) study the effect the establishment of a university has on the level of new business formation in the region. They find a positive effect on new business formation in innovative industries taken as a whole, but not for subsamples of innovative manufacturing and or knowledge-intensive services, which may be due to there being very few start-ups of these types. They conclude that setting up a university in a region contributes to that region becoming more of a knowledge-based economy.

In a study of Italian provinces, Piva, Grilli and Rossi-Lamastra (2011) find a significantly positive effect of the number of patents per capita as well as a weakly significant effect of the share of people with a tertiary degree in the region on the emergence of start-ups in innovative manufacturing. For new businesses in knowledge-intensive services, the number of patents per capita continued to be statistically significant, but the share of persons with a tertiary

⁹ The reason for these mixed results may be high correlation between the different indicators (see Section 4).

degree was not. Remarkably, the share of researchers in the resident population had no effect. Bonaccorsi et al. (2013) specifically investigate the effect of different types of knowledge and channels of knowledge transfer on the emergence of knowledge-intensive new businesses in Italy. The results of their analysis suggest that universities play a significant role, particularly if the university specializes in engineering or the medical sciences. Including alternative indicators for universities and regional innovation activity, the authors find positive effects for the presence of a university in the region, for the number of university graduates and university staff, for the number of publications that are listed in the ISI Web of Science, and for the number of patents. It is interesting that among these alternative indicators, the dummy variable for the mere presence of at least one university in the region leads to the highest coefficient. Other variables that have a statistically significant positive effect are the share of firms that belong to innovative industries in the regional firm population, population density, the share of unemployed persons in the regional workforce, value added per population, and the presence of a business incubator center in the region. Bonaccorsi et al. (2013) interact the different university-related indicators with dummy variables for location in either South Italy or North Italy. The results indicate that universities have an effect on the formation of innovative new businesses only in the southern part of the country, not in the economically more developed regions of northern Italy.

Summarizing the empirical evidence on the emergence of innovative new businesses in geographic space, there is strong indication for a very important positive effect of regional knowledge, especially of HEIs. The strength and significance of this positive effect, however, varies between subsectors of innovative industries¹⁰ as well as across regions and the reasons behind these variations are far from clear. Moreover, it is also less than clear what specific characteristics of universities and other public research institutions are most important for the emergence of innovative start-ups. Is it their mere presence in the region, their size in terms of the number of students and professors and the amount of R&D activity, or is it the quality of research that is important for the

¹⁰ A study of the United States by Bania, Eberts and Fogerty (1993) shows that there may also be considerable differences in the effect of different regional knowledge sources between four-digit industries that are classified as highly innovative.

emergence of innovative start-ups?¹¹ This lack of knowledge is chiefly due to data limitations, especially since what information there is usually covers only some selected aspects of what universities do. Since our data provide richer information on different types of university activities, we will attempt to identify which types of activity have the strongest effect on the regional formation of innovative new businesses.

3. Data and descriptive statistics

3.1 Data

Our data on start-ups are from the Founder Panel of the Center for European Economic Research (ZEW-Mannheim) and include nearly every newly founded independent firm during the period 1995–2008. These data are based on information from the largest German credit rating agency (Creditreform). It covers all private sectors in Germany and identifies innovative new businesses based on their affiliation with certain industries. We use the common classification of industries according to their presumed innovativeness and distinguish between (1) high-technology manufacturing industries that devote more than 8.5 percent of their input to R&D activity, (2) technologically advanced manufacturing industries with an R&D intensity between 3.5 and 8.5 percent, and (3) technology-oriented services, which cover some selected service industries closely related to innovation and new technology (Grupp and Legler 2000; OECD 2005; Gehrke et al. 2010). The technology-oriented services are a subgroup of knowledge-intensive services and include industries that are particularly related to innovation activity, such as “architectural and engineering activities,” “technical consultancy,” and “technical testing and analysis.” In addition, we run all models for those industries not classified as innovative or knowledge intensive. A main problem of such a classification is that industry affiliation can be “fuzzy,” seeing as there are innovative and not so innovative firms in all industries. Given the limited availability of data on

¹¹ An indication for different effects of size and quality-related university indicators is provided by Fritsch and Slavtchev (2007), who find that only the volume of external funds has a positive effect on regional innovation activity; no such positive effect can be found for indicators that are related to size, such as the number of professors and academic personnel or the number of students and of graduates.

innovation, however, this is often the only feasible way to identify new businesses as being innovative.¹²

Most of the information on the independent variables comes from one of two sources. Data on regional private-sector employment and R&D employment come from the German Employment Statistics, which covers all employees subject to compulsory social insurance contributions (Spengler, 2008). The second data source is the University Statistics of the German Federal Statistical Office, which provides detailed information about every university in Germany (Statistisches Bundesamt, various volumes). Data on unemployment are from the German Employment Agency (*Bundesagentur für Arbeit*). The spatial framework of the analysis is based on the 439 German districts (*Kreise*). To attain functional regions, we merged those districts that only encompass cities (*kreisfreie Stadt*) with the surrounding territorial districts, resulting in 325 regions.

The available data from the German University Statistics aid identification of five types of higher education institutions (HEI): regular universities (*Universitäten*), medical schools (*Universitätskliniken*), *Fachhochschulen*, which are also called universities of applied sciences, universities of public administration (*Verwaltungshochschulen*), and art colleges (*Kunsthochschulen*). Distinguishing between these types is important due to significant differences in both their research as well as their educational profiles. Medical schools at universities also have hospitals and are another type of specialized tertiary education. Due to their special characteristics, we count a medical school at a university as a separate university. The German *Fachhochschulen* are mainly intended to provide undergraduate education, while research is predominantly the domain of the regular universities. Moreover, *Fachhochschulen* offer predominantly engineering and management courses, while the regular universities usually cover a very broad range of academic disciplines, including a number of non-technical departments, the research results of which are rarely commercialized by private-sector innovators. The main mission of the universities of public administration is to educate civil servants for higher

¹² See Fritsch (2011) for the classification of German industries as “innovative,” “technologically advanced,” or “technology-intensive services.”

positions in public service, with a clear focus on law and management. Art colleges engage in very little research at all, according to the conventional understanding of the term, and are characterized by quite special forms of education. The more symbolic type of knowledge that these institutions generate and possess, however, could be important for the emergence of innovative new businesses. We categorize the arts colleges and the universities of public administration under “other” HEIs. Due to their rather special character, these two types of HEIs are, however, excluded in the calculation of all other university indicators such as number of professors, students, finance, etc.

No detailed regional data are available for the extra-university public research institutions. However, we know how many of such institutes there are in each region.¹³ Information about the number of patents is from the Patent Statistics. Patents are assigned to the region where the inventor has his or her residence.¹⁴ Tables A1 and A3 in the Appendix provide descriptive statistics for the variables used in the empirical analysis.

3.2 The spatial distribution of innovative start-ups in Germany

Figure 1 shows the geographic distribution of start-ups in high technology and technologically advanced manufacturing, as well as those in technology-intensive services. As seen in the figure, the emergence of an innovative new business in manufacturing is a rare event: 141 out of the 325 (42.4 percent per year and 120 regions (36.9 percent) have less than three start-ups in technologically advanced industries. The median value for the yearly number of high-technology start-ups is one and it is three for technologically advanced industries. On average, regions have less than two start-ups in high-technology

¹³ We account for all institutes of the four large public research organizations in Germany, i.e., the *Fraunhofer*, the *Helmholtz*, the *Leibnitz*, and the *Max Planck Society*. Data have been collected from different sources, mainly from publications of these organizations and the Federal Ministry of Education and Research. Since a number of these institutes have several locations, the publicly available information about their budgets and number of personnel cannot be meaningfully assigned to regions.

¹⁴ If a patent has more than one inventor, the count is divided by the number of the inventors involved and each inventor is registered with his or her share of that patent.

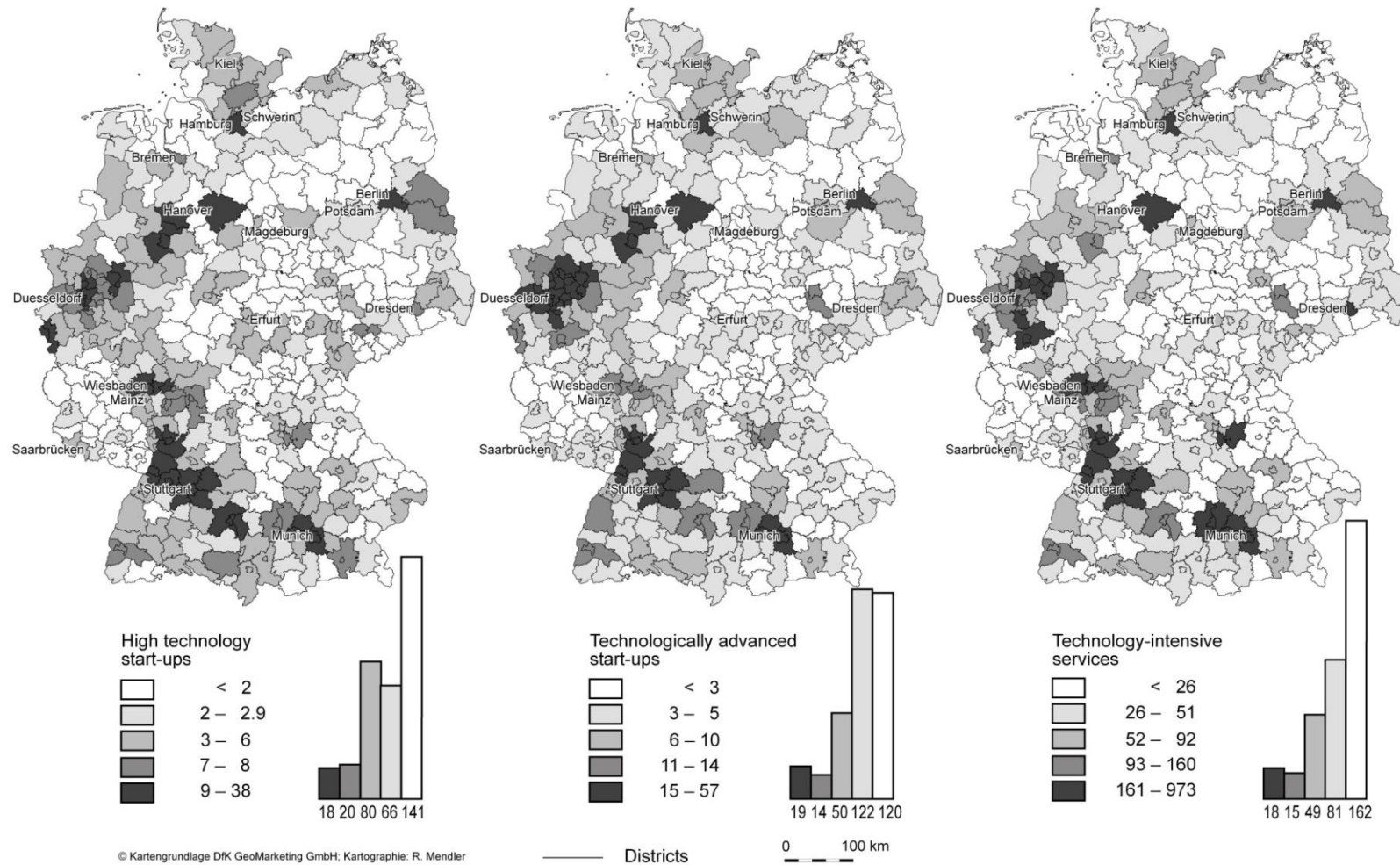


Figure 1: Average yearly number of start-ups in innovative and knowledge intensive industries, 1995–2008

industries. The number of new businesses in technology-oriented services is considerably larger (median value of 26) but geographic distribution is highly uneven in this sector. Regions with a relatively high number of innovative start-ups tend to be larger cities with a rich infrastructure of public research institutions, particularly universities. The basic pattern of the geographic distribution is largely the same for the start-up rate that relates the number of innovative start-ups to the labor force.

Table 1: Gini coefficients for the geographic concentration of start-ups and related variables

<i>Variable</i>	<i>Gini coefficient</i>
<i>Number of new businesses in:</i>	
- high-technology industries	0.586
- technologically advanced industries	0.529
- technology-intensive services	0.545
- non-innovative industries	0.481
- all industries	0.483
Number of R&D employees	0.616
Number of higher education institutions (HEIs)	0.477
Number of regular universities	0.627
Number of <i>Fachhochschulen</i>	0.447
Number of other HEIs	0.831
Number of professors	0.612
Number of graduates	0.654
Number of extra-university public research institutes	0.901

Looking at the geographic concentration of new businesses in the different industries (Table 1), we find the highest value of the Gini coefficient for start-ups in high-technology manufacturing industries followed by those in technology-oriented services and technologically advanced industries. Compared to the concentration of start-ups in all industries and in non-innovative industries, the difference in the respective Gini coefficients is not very large. The numbers of professors, graduates, private-sector R&D employees, and regular universities show about the same degree of geographic concentration, while the

concentration of the *Fachhochschulen* is much less pronounced. Remarkably, geographic concentration of extra-university institutes for public research as well as other HEIs (arts colleges and universities of public administration) is much higher than concentration of the regular universities and the *Fachhochschulen*. Most of the HEIs (56 percent) and non-university research institutes (69.5 percent) are located in regions commonly classified as agglomerations.¹⁵ 79 of the 272 extra-university public research institutes (29 percent) are in moderately congested regions and only four of these institutes (1.5 percent) are located in areas that can be regarded as “rural.” The share of HEIs in moderately congested and rural regions is 35.7 percent and 8.4 percent, respectively.¹⁶

4. Empirical approach

4.1 Estimation strategy

As dependent variables, we use the number of start-ups in high-technology manufacturing industries, in technologically advanced manufacturing industries, in technology-oriented services, and in those industries that are not classified as innovative or knowledge intensive. Due to the count character of these variables, we employ a negative binomial estimation technique to analyze the impact of different variables on the formation of innovative start-ups. Because we find a relatively high share of observations with no regional start-up in high-technology manufacturing in a year (27.78 percent), we could be facing the “too many zero values” problem. A possible solution to this problem is to apply the zero-inflated version of the negative binomial method, which includes only a selection of “true” zero values in the estimation. In such a procedure, regions where one can never expect the event of interest, that is, the formation of an innovative start-up, are excluded from the estimation. The zero-inflated negative binomial method requires an assumption for identifying and selecting the “true” zero values. Since our data show that all regions in Germany have at least one

¹⁵ This common classification of German regions by the Federal Office for Building and Regional Planning is based on a region’s population density and settlement structure. For details, see Federal Office for Building and Regional Planning (2003).

¹⁶ The highest number of HEIs can be found in Berlin (34 HEIs), followed by Munich (19), Hamburg (17), and Stuttgart (10). The regions with the highest number of non-university institutions for public research are Berlin (26), Munich (20), and Dresden (17).

start-up in high-technology industries from time to time, all the zero values in our data have to be regarded as “true” and thus the zero-inflated negative binomial estimation method is inappropriate here.¹⁷ For the technologically advanced start-ups, the share of observations without a new business in a year is 13.54 percent and for technology-intensive services it is 0.07 percent, suggesting that there is no “too many” zero values problem.

We have a time series of yearly observations for a period of 14 years and thus we can apply panel estimation techniques. Since many of the potential explanatory variables (e.g., number of universities in the region) show no or not much of variation over time, a fixed effects estimator that would account for unobserved regional characteristics is not appropriate because a considerable part of the influence of such variables is captured by the fixed effects. For this reason, we use a random effects estimator but also present some examples of fixed effects estimations in the Appendix. Since the standard statistical software packages do not provide spatial lag and spatial error corrections for negative binomial panel models, we include dummy variables for the German Federal States (*Laender*) in order to control for effects of the wider regional environment. Since the German Federal States are an important policy-making level, this variable may also indicate the effect of policy measures at this level.¹⁸ Year dummies are included as controls for time-specific effects. All independent variables are lagged by one year.

A severe problem of the empirical analysis is the high correlation among most of the indicators for the universities (see Table A4 in the Appendix). These pronounced correlations are to a considerable extent caused by a variation of these variables with size due to complementarity, for example, having a large number of students means a larger teaching staff and a greater amount of

¹⁷ A plausible assumption for the selection of “true” zero values could be that the emergence of an innovative start-up in a region requires the presence of at least one university or of a non-university public research institute. This assumption, however, is not unproblematic because it already implies the general hypothesis that innovative start-ups emerge from public research. Running a zero-inflated negative binomial model with the variable “presence of a university or non-university public research institute in the region” for the selection of the “true” zero values, we find that a Vuong test suggests that doing so is not a significant improvement over a standard negative binomial model.

¹⁸ A great deal of the financing and legal framework for universities and non-university public research institutes is the responsibility of the Federal States in Germany. Most of the Federal States also operate their own programs for promoting entrepreneurship.

resources. We deal with this problem as follows. In a first step, we estimate a baseline model without the indicators for universities and non-university public research institutes. In a second step, we add only one of these indicators at a time to this model. Our measure for the impact of these indicators is change in the AIC (Akaike Information Criterion)¹⁹ (see Greene, 2008) compared to the baseline model. A decrease in the AIC value due to the inclusion of an additional variable indicates a better fit of the model in terms reducing the remaining “unexplained” variance. An increase in the remaining variance leads to a higher AIC value. In a final step, we perform a factor analysis for the variables that represent public research in order to aggregate this information and add a factor that represents the regional HEIs to the variables of the baseline model. Since the dependent as well as the independent variables are logged, the values of the estimated coefficients can be interpreted as elasticities that indicate the relative importance of the respective effect.

4.2 Independent variables and expected results

In our empirical analyses of the factors that determine the emergence of innovative start-ups we expect significant effects for all those variables that can be supposed to be generally conducive to new business formation (see Section 2.2.1). We include the number of regional workforce, which represents the pool of potential entrepreneurs and also reflects economies of size and agglomeration effects. The regional workforce is divided into the number of private-sector R&D employees, the number of employed persons excluding R&D employees, and the number of persons registered as being unemployed. The number of R&D employees is an important part of the knowledge pool in the region. Since the number of R&D employees is highly correlated with the number of people with a tertiary degree, we do not include an indicator for the share of the workforce holding a tertiary degree. We expect a positive effect on the emergence of innovative start-ups for the number of employed people, particularly the number of R&D employees, but the impact of the number of unemployed people is a priori unclear. On the one hand, innovative start-ups

¹⁹ The AIC is a measure of the relative goodness of fit of a statistical model that accounts for the number of independent variables included in the model. For details, see Akaike (1974) and Greene (2008).

can, of course, be set up by the unemployed. On the other hand, unemployed people have a relatively low propensity for starting their own business (Fritsch and Falck, 2007), and this may be particularly true when it comes to innovative ventures that primarily represent opportunity, rather than necessity, entrepreneurship and require a relatively high level of qualification. Moreover, a high number of unemployed people in a region can be viewed as an indication of bad economic conditions and, therefore, poor prospects for success, which may prevent potential founders from setting up a firm in the region (Reynolds et al. 1994; Carree 2002; Sutaria and Hicks, 2004).

We expect that founders have a strong tendency to start a business in the industry with which they were previously affiliated (Fritsch and Falck, 2007) and, in turn, this should result in a positive effect for the employment share of these industries. Hence, we include the employment share in the respective group of industries (high-technology, technologically advanced, technology-oriented services, non-innovative industries). This variable also reflects regional specialization in the respective group of industries as well as the available industry-specific knowledge. The share of employees in small establishments (those with fewer than 50 employees) should have a positive effect due to a generally higher propensity of small-firm employees to engage in start-up.²⁰ A positive effect can also be expected for the number of private R&D employees in adjacent districts, as these represent spatial knowledge spillovers over relatively short distances (Anselin, Varga and Acs, 1997; Asheim and Gertler, 2005). We also expect a positive effect in the number of patents per 1,000 employees, which is a general measure for regional knowledge and R&D activity.²¹

²⁰ Employment in industry groups and small-firm employment are entered in the regressions as shares in overall regional employment because including these numbers would lead to double counting with the overall number of employees and cause multicollinearity.

²¹ We do not distinguish between patents registered by HEIs, non-university public research institutes, or the private sector for several reasons. One reason is that universities and other public research institutes in Germany are to different degrees selective with respect to patenting inventions so the number of patents is not a meaningful indicator of innovative output. A second reason is a change in the legal framework for university patenting that led to considerable change in patenting behavior during the period of analysis (for details, see Proff, Buenstorf and Hummel, 2012).

Since the presence of universities and other kinds of public research institutes in the region may be an important source of knowledge for innovative start-ups, we expect a positive effect. Regional proximity to these institutions may be important because a great deal of their knowledge is of a tacit nature and tends to be “sticky,” that is, it is regionally bound. This stickiness of regional knowledge is reflected in the pronounced tendency of spin-offs from universities and other public research institutions to locate close to their incubator organization. The positive effect of universities and other public research institutions should be stronger for new businesses in high-technology manufacturing industries than for start-ups in technologically advanced manufacturing or in technology-oriented services because many parts of high technology manufacturing can be regarded as science based. Along these lines, HEI presence may be insignificant for new businesses in non-innovative industries. To account for the possibility of spatial knowledge spillovers, we include indicators for public research and tertiary education in adjacent regions. If these indicators are statistically significant, their effect should be positive but less pronounced than for HEI and other public research institutes actually located within the respective region due to the sticky character of the knowledge.

Indicators that reflect the universities and non-university public research institutes are:

- The presence of at least one HEI (yes = 1; no = 0), as well as the number of HEIs in the region and in adjacent regions. To the extent that HEIs are specialized in certain academic disciplines, the number of HEIs can be viewed as an indication of the variety of academic knowledge present in a region.
- The presence of at least one extra-university public research institute (yes = 1; no = 0) and the number of such institutes in the region and in adjacent regions. As with the number of HEIs, the number of extra-university research institutes may reflect the variety of research fields.
- The numbers of students, graduates, Ph.D. students, and professors. These variables reflect different aspects of the HEI's size. The number of students and graduates indicates a contribution to workforce's education (i.e., its

qualifications); the number of professors and Ph.D. students primarily signifies the volume of research being conducted.

- The amount of internal financing as well as the amount of third-party funds (external funds). To the extent that third-party funds come from private firms, they most likely reflect contract R&D and cooperation with these firms. Because third-party funds are nearly always allocated via some kind of competitive procedure, they can also be regarded as an indication of research quality.
- The amount of internal funds and third-party funds per professor. These indicators represent the resource endowment and the quality of research largely independent of the HEI's size.

If public and private research in a region is conducive to the emergence of innovative start-ups, we may expect a concentration of this kind of new business in larger cities and agglomerations because both public research institutes as well as private-sector R&D tend to be concentrated in such high-density areas. Other reasons for expecting a relatively high number of innovative start-ups in larger cities include agglomeration economies, such as large and diversified input markets and rich opportunities for direct face-to-face contacts, which can be assumed conducive to the transfer of knowledge. We do not include a measure for population density in our standard models because of its close statistical relationship with other variables that would lead to severe multicollinearity problems. Due to its close correlation with many other factors that may be the "true" determinants of innovative start-ups, including population density could obscure the effects that these other factors have on the emergence of innovative start-ups. However, in order to analyze the influence of agglomeration effects, we run our models for groups of regions having various population density (see Section 5.2).

5. Results

We first report the results for the baseline model with and without indicators for public research (Section 5.1). Given the close correlation between the different measures for public research, we perform a factor analysis and include a factor

that represents the overall activities of regional HEIs in the model (Section 5.2). All models are estimated for four groups of industries: high-technology manufacturing, technologically advanced manufacturing, technology-oriented services, and non-innovative or knowledge-intensive industries. Section 5.3 sets out the results of a number of extensions and robustness checks.

5.1 Results for the baseline model and indicators for regional public research

In our baseline model we find positive and statistically significant effects for the number of employed persons, excluding R&D employees, as well as for the employment share for the number of start-ups in all four industry groups (Table 2). Matching our expectations, the coefficient for the number of R&D employees has the highest value for new businesses in high-technology manufacturing industries followed by those in technologically advanced manufacturing and in technology-oriented service; it is not statistically significant for start-ups in non-innovative industries. The fact that the number of unemployed people has an effect only on start-ups in non-innovative industries clearly indicates that new businesses set up by unemployed people tend to occur in these industries. The share of employees in establishments with fewer than 50 employees also has a statistically significant positive effect except for start-ups in technologically advanced manufacturing. This positive effect may be an indication that founders of new businesses were previously employed in small firms or that the presence of industries with low minimum efficient size is conducive to start-ups (Fritsch and Falck, 2007).

The number of patents per 1,000 employees has a positive effect on start-ups in high-technology manufacturing and in technology-oriented services but it is not statistically significant for start-ups in technologically advanced manufacturing (Table 2). The relationship with the number of start-ups in non-innovative industries is statistically significant but with a negative sign. This clearly indicates the importance of regional knowledge for the formation of innovative new businesses. We find no significantly positive effect for the number of R&D employees in surrounding regions, suggesting that interregional

Table 2: Baseline model for explaining number of start-ups in different groups of industries

	High-technology manufacturing	Technologically advanced manufacturing	Technology-oriented services	Non-innovative industries
Number of employed persons, excluding R&D employees (ln)	.0347*** (3.26)	.0311*** (3.56)	.0304*** (7.12)	.5467*** (19.76)
Number of R&D employees (ln)	.00002*** (4.11)	7.97e-06*** (2.45)	3.54e-06** (1.92)	6.89e-07 (0.88)
Number of unemployed (ln)	.0110 (0.55)	.0095 (0.59)	.0042 (1.00)	.0067*** (7.14)
Share of employees in high-technology manufacturing industries (ln)	.0971*** (7.02)	–	–	–
Share of employees in technologically advanced manufacturing industries (ln)	–	.0199** (2.09)	–	–
Share of employees in technology-oriented service industries (ln)	–	–	.0198*** (2.76)	–
Share of employees in non-innovative industries	–	–	–	.0724*** (2.50)
Share of employees in establishments with fewer than 50 employees (ln)	.2427** (1.99)	.0625 (1.57)	.2322*** (2.92)	.2665*** (11.05)
Number of R&D employees in adjacent regions	.0194 (0.84)	-.0102 (0.56)	-.0214*** (3.69)	-.0040* (1.64)
Number of patents per 1,000 employees (ln)	51.3587*** (3.38)	-.3425 (0.03)	17.5053*** (3.34)	-2.4442*** (0.94)
Constant	.7197*** (10.26)	1.3684*** (13.82)	2.6735*** (29.67)	-1.4930*** (39.38)
Wald chi2	573.25***	479.07***	899.48***	2756.17***
Dummies for Federal States	Yes***	Yes***	Yes***	Yes***
Dummies for years	Yes***	Yes***	Yes***	Yes***
Number of observations (number of zeros)	4,550 (1,264)	4,550 (616)	4,550 (3)	4,550 (0)
Log likelihood	-8,489.2698	-10,252.936	-16,669.051	-20695.383
AIC	17,042.54	20,563.87	33,402.1	41,455.08
Pseudo R2	.6342	.5545	.7431	.6518
McFadden's R2	.105	.106	.109	.178
Notes: The dependent variable is the number of start-ups per year in the respective group of industries. Negative binomial panel regression with random effects. Z-values in parentheses. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level.				

spillovers from R&D employment are irrelevant for the emergence of new businesses, even in our rather narrowly defined regions. Including measures for the concentration of the regional industry structure that would indicate an effect of spatial clustering does not lead to any plausible or statistically significant results.

Table 3: Effect of including indicators for public research in the baseline model

	High-technology manufacturing	Technologically advanced manufacturing	Technology-oriented services	Non-innovative industries
Institution for tertiary education (HEI) (yes = 1; no = 0)	-28.66 .3014 (5.45)***	-14.81 .1574 (4.11)***	-11.62 .0767 (3.68)***	1.99 .0010 (0.12)
Number of HEIs (ln)	-83.56 .3907 (9.75)***	-105.23 .3169 (10.68)***	-28.74 .1037 (5.56)***	24.75 .0097 (1.24)
Regular university (yes = 1; no = 0)	-25.81 .3004 (5.31)***	-30.81 .2178 (5.71)***	-8.33 .0655 (3.21)***	0.57 -.0102 (1.20)
Number of regular universities (ln)	-33.63 .5633 (5.99)***	-46.19 .4410 (6.86)***	-3 .0884 (2.25)**	23.86 .0241 (1.56)
<i>Fachhochschule</i> (yes = 1; no = 0)	-16.11 .2216 (4.07)***	-17.33 .1652 (4.40)***	-5.31 .0557 (2.70)***	1.97 .0015 (0.17)
Number of <i>Fachhochschulen</i> (ln)	-55.93 .4894 (7.85)***	-60.07 .3553 (8.03)***	-13.23 .1091 (3.93)***	26.22 .0026 (0.24)
Other HEIs (yes = 1, no = 0)	-6.83 .0931 (6.68)***	-5.15 .0612 (5.76)***	-1.36 .0231 (3.71)	2.35 -.0024 (0.91)
Number of other HEIs (ln)	-15.41 .1277 (7.44)***	-23.5 .0923 (7.24)***	-3.43 .0116 (1.55)	7.33 .0045 (1.52)
Number of students (ln)	-41.57 .0467 (6.61)***	-30.63 .0334 (5.80)***	-14.79 .0128 (4.09)***	26.83 -.0045 (1.71)*
Number of graduates (ln)	-36.56 .0541 (6.16)***	-29.69 .0397 (5.68)***	-26.78 .0192 (5.34)***	1.92 .0007 (0.30)
Number of Ph.D. students (ln)	17.45 .0555 (4.53)***	-36.41 .0609 (6.26)***	-7.88 .0162 (3.14)***	356.59 -.0079 (1.87)*
Number of professors (ln)	-36.99 .0742 (6.22)***	-36.31 .0607 (6.28)***	-19.2 .0240 (4.59)***	358.87 -.0050 (1.10)
Amount of regular funds (ln)	-28.21 .0364 (6.44)***	-25.54 .0224 (5.27)***	-19.34 .0103 (4.62)***	359.58 .0009 (0.71)
Amount of external funds (ln)	-32.23 .0402 (6.47)***	-29.35 .0261 (5.63)***	-16.64 .0105 (4.31)***	359.17 .0011 (0.96)
Regular and external funds (ln)	-34.19 .0356 (6.62)***	-30.47 .0231 (5.73)***	-20.58 .0099 (4.75)***	359.16 .0032 (0.96)
Regular funds per professor (ln)	-19.73 .0530 (4.82)***	-21.08 .0399 (4.83)***	-14.42 .0169 (4.06)***	358.39 .0033 (1.30)
External funds per professor (ln)	-26.04 .0745 (5.46)***	-17.37 .0457 (4.42)***	-7.46 .0159 (3.08)***	358.8 .0026 (1.14)
Regular and external funds per professor (ln)	-29.99 .0616 (5.82)***	-21.80 .0390 (4.90)***	-13.66 .0161 (3.96)***	358.85 .0061 (1.11)
Non-university public research institute (yes = 1; no = 0)	-61.09 .7171 (7.95)***	-93.40 .8023 (9.51)***	-61.23 .6118 (8.18)***	1.67 -.0315 (0.58)
Number of non-university public research institutes (ln)	-48,24*** .5337 (7.19)	-58,04*** .5385 (7.90)	-17,4*** .2870 (4.54)	360,06 .0081 (0.16)
Number of HEIs in adjacent regions	-12.04*** .2197 (3.77)	-23.20*** .2662 (5.04)	-31.26*** .2924 (5.86)	1 .0194 (1.00)
Non-university public research in adjacent regions (yes = 1; no = 0)	1.21 .3161 (0.91)	-0.02 .4639 (1.46)	0.37 .4007 (1.32)	1.7 -.0959 (0.55)
Number of non-university public research institutes in adjacent regions	-7,87 -.0255 (.59)	-2,52 -.0296 (0.75)	0,44 .0430 (1.13)	348 .0810 (3.42)***

Notes: First row: Change in the AIC value due to the inclusion of the variable. Second row: Estimated coefficient and z-value in parentheses. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level.

When we include indicators for public research in these models, we find the highest increases of explained variance, as indicated by reduction of the AIC values, for the number of such institutions in a region, i.e., the number of HEIs, and the number of non-university public research institutes (Table 3). The effect of the “other” HEIs (arts colleges and universities of public administration) is considerably weaker than the effect of regular universities and *Fachhochschulen*. Surprisingly, indicators for the number of professors and the number of graduates, as well as for the amount and type of available financial resources, have a much smaller impact. The number of HEIs, and of non-university public research institutes in adjacent regions, is intended to indicate spatial spillover effects. The results for the HEIs in adjacent regions suggest that there are such spillover effects, but that their importance for new business formation is considerably weaker than the effect of HEIs located in the same region. There is no statistically significant effect of the presence and number of non-university research institutes in adjacent regions on start-ups in innovative industries. It is remarkable that adding measures for public research institutes to the baseline model for start-ups in non-innovative industries degrades model fit. This clearly indicates that public research is rather unimportant for new business formation in these sectors.

Since all independent variables are logged, the estimated coefficients can be interpreted as elasticities and used as indicators for the relative importance of the different variables. Comparing the estimated coefficients of the diverse measures for public research with the coefficients for private-sector R&D, such as the number of R&D employees, we find that many of the public research indicators are much more important. In most cases, the effect of the indicators for public research institutions is strongest for start-ups in high-technology manufacturing and weakest for new businesses in technology-oriented services.

5.2 Aggregation of indicators for regional public research

We conducted factor analyses to aggregate the information provided by the diverse indicators for HEIs. The factor analyses showed that different types of HEI activity, such as education and research, could not be meaningfully

separated into different factors. Hence, we generated only one factor to represent regional HEIs, which is based on the number of graduates, the number of Ph.D. students, the number of professors, the amount of regular funds, and the amount of external funds (see Table A5 in the Appendix). This factor for HEI activity in the region and in adjacent regions was then included in the baseline model. Since our information about the non-university public research institutes is limited, we included the number of such institutes in the region and in the adjacent regions in order to represent this part of public research.

The results of the baseline model with the aggregate indicators for public research included are displayed in Table 4. A main difference between these results and those from the baseline model without indicators for public research (Table 2) is that the number of regional private-sector R&D employees loses statistical significance, whereas both indicators for public research in the region are highly significant with the expected sign in the models for innovative and knowledge-intensive industries, but not in the estimate for non-innovative industries. However, it is problematic to conclude from this result that public R&D is more important for innovative start-ups than private-sector R&D due to the considerable correlation between the indicators for the two types of activities.²² Presumably, the main source of these correlations is that there are pronounced spatially concentrated knowledge spillovers between these two types of R&D (Fritsch and Slavtchev, 2007). Such spatially bounded knowledge spillovers are one reason for the co-location of public and private-sector R&D facilities. Moreover, both types of R&D prefer the same kind of region, mainly larger cities. The relationship between public and private R&D is complex. Public institutions of education and research may provide important inputs for private-sector R&D, and R&D in both sectors may be interrelated, particularly at the regional level.

²² The correlation coefficient between the aggregate indicator for the regional HEIs (the number of non-university public research institutes) and the number of private-sector R&D employees is 0.465 (0.596); see Table A2 in the Appendix. The correlation between the regional number of private-sector R&D employees and the aggregate indicator for HEIs (the number of non-university public research institutes) in adjacent regions is 0.323 (-0,021).

Table 4: Baseline model with aggregate indicators for public research

	High- technology manufacturing	Technologically advanced manufacturing	Technology- oriented services	Non-innovative industries
Number of employed persons, excluding R&D employees (ln)	.0251** (2.39)	.0229*** (2.66)	.0277*** (6.43)	.5262*** (18.93)
Number of R&D employees (ln)	-9.86e-08 (0.03)	-2.83e-06 (1.01)	1.15e-07 (0.07)	4.33e-07 (0.87)
Number of unemployed (ln)	-.0189 (0.99)	-.0088 (0.59)	-.0056 (1.28)	.0061*** (6.20)
Share of employees in high-technology manufacturing industries (ln)	.0945*** (6.97)	—	—	—
Share of employees in technologically advanced manufacturing industries (ln)	—	.0200** (2.14)	—	—
Share of employees in technology-oriented service industries (ln)	—	—	.0186*** (2.58)	—
Share of employees in non-innovative industries	—	—	—	.0727*** (2.46)
Share of employees in establishments with fewer than 50 employees (ln)	.3860*** (3.15)	.0694* (1.80)	.4036*** (4.83)	.2902*** (11.44)
Number of R&D employees in surrounding regions	.0321 (1.48)	.0021 (0.13)	-.0131** (2.26)	-.0034* (1.73)
Number of patents per 1,000 employees (ln)	48.9386*** (3.30)	.8756 (0.09)	19.999*** (3.82)	-3.6376 (1.19)
Aggregate indicator of HEIs in the region	.1917*** (6.44)	.1481*** (6.21)	.0696*** (5.16)	.0031 (0.25)
Number of non-university research Institutes (ln)	.4834*** (6.74)	.4796*** (7.30)	.2777*** (4.39)	-.0011 (0.02)
Aggregate indicator of HEIs in adjacent regions	.0425 (1.22)	.0439 (1.59)	-.0140 (1.04)	.0285*** (3.02)
Number of non-university research institutes in adjacent regions (ln)	.0017 (0.04)	-.0102 (0.29)	.0665* (1.84)	.0873*** (3.77)
Constant	.7922*** (10.33)	1.4283*** (14.43)	2.5437*** (29.93)	-1.2388*** (39.06)
Wald chi 2	737.74***	646.67***	969.70***	2835.25***
Dummies for Federal States	Yes***	Yes***	Yes***	Yes***
Dummies for years	Yes***	Yes***	Yes***	Yes***
Number of observations (number of zeros)	4,550 (1,264)	4,550 (616)	4,550 (3)	4,550 (0)
Log likelihood	-8,442.796	-10,201.906	-16,644.181	-20,684.196
AIC (change in AIC compared to the baseline model in Table 3)	16,957.59 (-84.95)	20,469.81 (-94.06)	33,360.36 (-41.74)	41,412.86 (-42.22)
Pseudo R2	.6218	.5787	.4956	.7060
McFadden's R2	.124	.125	.139	.180
Notes: The dependent variable is the number of start-ups per year in the respective group of industries. Negative binomial panel regression with random effects. Z-values in parentheses. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level.				

It is remarkable that the number of non-university public research institutes has a considerably stronger effect than the aggregate indicator for the regional HEIs. The relatively high coefficients for the number of non-university public research institutions in the region may, to a degree, reflect the concentration of this type of public research in high-density areas, which are also the areas where most of the innovative start-ups occur, and therefore could be an overestimation of their effect. Measures for public research in adjacent regions are not statistically significant for high-technology manufacturing or for technologically advanced industries. We find a weak significant effect of the number of non-university public research institutes in adjacent regions for start-ups in technology-oriented services. Surprisingly, the estimates for start-ups in non-innovative industries indicate a pronounced effect of HEIs and of the number of non-university research institutes in adjacent regions, but not for public research in the same region; however, this finding could be a statistical artifact caused by correlation among explanatory variables. The inclusion of the indicators for public research leads to large reductions in the AIC value in all four models, particularly in the estimates for new businesses in high-technology manufacturing and in technologically advanced manufacturing industries. All in all, these results confirm the very important role of public research identified in Section 5.1.

5.3 Extensions and robustness checks

We performed a number of robustness checks in order to test the stability of the results.²³ First, we ran the models with fixed effects. As expected, a fixed effects panel estimator does not lead to meaningful results. In these models, many of the indicators for public research are not statistically significant, which is obviously due to low levels of variation over time. Second, given the strong effect that we found for the presence of at least one HEI or non-university public research institute, we ran the regressions for only those regions that have at least one such institute (about 62 percent of all regions). Considerable differences in the estimates from the models for all regions could indicate that the coefficients for the number of institutes mainly reflect the presence of at

²³ The results are available from the authors upon request.

least one such institute. We find, however, that the results are similar. Excluding regions with a relatively high number of HEIs and extra-university public research institutes, such as Berlin and Munich, did not produce any significantly different results either. Third, the models were run separately for East and West Germany, and again there was not much difference in the results, indicating that the commercialization of knowledge through the formation of innovative new businesses follows the same pattern in both parts of the country.

Finally, in order to further analyze the influence of agglomeration effects, we sorted the regions based on population density into three groups of equal size and ran the regressions separately for regions with relatively low, medium, and high level of population density. We found that the coefficient for the aggregate effect of HEIs is highest in regions with low population density, somewhat lower in regions with medium density, and relatively low in high density areas. These results suggest that HEIs may have a particularly pronounced effect in low-density regions and that their effect in high-density areas is somewhat obscured by other factors, making it difficult to identify their precise role using this type of analysis. We also find that the number of non-university public research institutes has a statistically significant effect only in regions with relatively high population density. One main reason for this result may be the rather high concentration of these institutions in agglomerations and that there are nearly no non-university public research institutions in rural areas. Another reason could be relatively high correlation between the aggregate indicator for HEIs and the number of non-university research institutes.²⁴

6. Summary and conclusions

We analyzed a rich dataset containing particularly detailed information about institutes of tertiary education in German regions. According to our empirical analysis, there is a strong relationship between the mere presence of universities and other types of public research institutes and the emergence of new businesses in industries commonly classified as innovative. Other indicators that reflect the size of these institutions or the quality of research are

²⁴ The coefficient of correlation between these two indicators in the overall sample is 0.488 (see Table A2 in the Appendix).

also statistically significant, but have a considerably smaller impact. We also find some positive effects for public research institutes in adjacent regions, thus indicating interregional spillovers, but these effects are modest and often not statistically significant. The impact of public research is particularly pronounced for start-ups in high-technology and technologically advanced manufacturing industries and tends to be considerably less important for new business formation in technology-oriented services. Our results suggest that public research has hardly any impact on new business formation in industries that are not particularly innovative.

Due to the pronounced correlations between many of the various indicators for public research, however, we were not able to exactly determine which characteristics of public research institutions are the most important with regard to the emergence of innovative new businesses. In particular, even factor analysis did not reveal separate factors representing different aspects of public education and research. Moreover, we do not think that even more sophisticated econometric methods applied to aggregate data for whole regions can overcome the problem of strong interrelation between the variables for public research. Further insights that may provide more detailed policy guidance are mainly to be expected from analyzing micro data and by means of qualitative analysis on a case-study basis. Despite such limitations, however, the main conclusion from our analysis is crystal clear: public research in a region is a main source of innovative start-ups and the regional distribution of innovative new businesses is highly influenced by the regional distribution of public research institutions. Hence, policy aimed at increasing and/or improving public research may be crucial for long-term regional development (Carree, Della Malva and Santarelli, forthcoming). However, this in no way means that other aspects of regional conditions are unimportant. On the contrary, there are strong indications that the effect of public research on regional development may vary considerably across regions. Whether this is due to characteristics of the research institutes or to other region-specific factors (e.g., Astebro and Bazzazian, 2011; Bonaccorsi, et al., 2013; Piva, Grilli and Rossi-Lamastra, 2011) is an important avenue for further research.

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Appendix

Table A1: Descriptive statistics for the relevant variables

	Mean	Minimum	Maximum	Standard deviation
Number of start-ups in high-technology manufacturing industries ^a	3	0	58	4.820
Number of start-ups in technologically advanced manufacturing industries ^a	5	0	85	7.070
Number of start-ups in technology-intensive service industries ^a	50	0	1,386	95.300
Number of start-ups in non-innovative industries ^a	700	75	13,904	1,065
Number of start-ups in all private industries ^a	758	78	14,992	1,165
Number of employed persons, excluding R&D employees ^b	63,110	7,090	982,295	91,112
Number of unemployed persons ^c	12,652	1,323	310,661	18,839
Number of R&D employees ^b	2,331	60	62,469	5,315
Number of R&D employees in neighboring regions ^b	12,205	126	245,205	18,882
Share of employees in high-technology manufacturing industries ^b	0.010	0	.221	0.024
Share of employees in technologically advanced manufacturing industries ^b	0.037	0	.692	0.069
Share of employees in technology-oriented service industries ^b	0.035	0	.200	0.048
Share of employees in non-innovative industries ^b	0.915	0.245	1	0.120
Number of patents per 1,000 employees ^d	1.937	0.009	16.724	1.572
Share of employees in establishments with fewer than 50 employees ^b	0.51	0.13	0.77	0.09

Notes: a) Source: ZEW Foundation Panel; b) Source: Social Insurance Statistics; c) Source: Federal Employment Agency; d) Source: Patent statistics.

Table A2: Correlations for the variables in the baseline model

[illegible]

Table A3: Descriptive statistics for the indicators for universities and other public research institutes

	Mean	Minimum	Maximum	Standard deviation
Number of (HEIs)	1.811	0	34	3.285
Number of regular universities	0.425	0	7	.907
Number of <i>Fachhochschulen</i>	0.856	0	27	1.599
Number of other HEIs	.422	0	6	.927
Number of students	10,512	9	143,540	18,088
Number of graduates	1,331	1	20,562	2,189
Number of Ph.D. students	305	1	3,038	368.432
Number of professors	222.851	1	2975	333.115
Amount of regular funds (1,000 €)	90,738	1	1,146,295	172,158
Amount of regular funds per professor (1,000 €)	200.73	.091	3782.73	293.53
Amount of external funds (1,000 €)	24,701	3.07	314,651	40883
Amount of external funds per professor (1,000 €)	57.08	0.111	980.49	61.13
Number of non-university public research institutes	0.837	0	26	2.6746
Number of HEIs in adjacent regions	48.96	2	15	24.372
Number of non-university public research institutes in adjacent regions	20.923	0	92	13.010

Source: German University Statistics.

Table A4: Correlations between different indicators for universities and other public research institutes in the region

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	University (yes=1; no=0)	1.00																		
2	Number of HEIs (ln)	.490	1.00																	
3	Regular university (yes=1; no=0)	.553	.629	1.00																
4	Number of regular universities (ln)	.216	.699	.391	1.00															
5	<i>Fachhochschule</i> (yes=1; no=0)	.817	.514	.431	.236	1.00														
6	Number of <i>Fachhochschulen</i> (ln)	.327	.813	.391	.648	.401	1.00													
7	Number of other HEIs	.252	.731	.361	.707	.221	.625	1.00												
8	Number of students (ln)	.728	.621	.542	.347	.638	.439	.366	1.00											
9	Number of graduates (ln)	.687	.656	.557	.377	.605	.462	.393	.973	1.00										
10	Number of Ph.D. students (ln)	.351	.710	.671	.546	.288	.505	.511	.667	.705	1.00									
11	Number of professors (ln)	.652	.673	.586	.409	.613	.486	.403	.956	.954	.741	1.00								
12	Amount of regular funds (ln)	.579	.745	.632	.446	.467	.502	.455	.776	.792	.759	.817	1.00							
13	Amount of external funds (ln)	.527	.744	.657	.467	.459	.513	.464	.766	.783	.793	.832	.946	1.00						
14	Amount of regular and of external funds (ln)	.532	.743	.646	.459	.461	.512	.461	.764	.780	.782	.828	.954	.994	1.00					
15	Amount of regular funds per professor (ln)	.540	.709	.618	.420	.426	.465	.436	.741	.751	.759	.781	.961	.908	.913	1.00				
16	Amount of external funds per professor (ln)	.494	.700	.656	.440	.408	.468	.436	.725	.739	.808	.785	.916	.975	.960	.911	1.00			
17	Amount of regular and of external funds per professor (ln)	.514	.723	.647	.438	.436	.484	.444	.745	.758	.793	.804	.940	.981	.983	.936	.913	1.00		
18	Number of non-university public research institutes (ln)	.079	.395	.171	.474	.125	.451	.451	.181	.196	.325	.222	.207	.228	.221	.206	.211	.216	1.00	
19	Number of HEIs in adjacent regions	.142	.232	.010	.172	.159	.220	.191	.187	.183	.147	.181	.103	.093	.092	.108	.081	.090	.042	1.00
20	Number of non-university public research institutes in adjacent regions (ln)	.021	-.001	-.015	-.026	-.001	-.003	.025	-.003	-.008	-.074	-.029	-.043	-.055	-.054	-.036	-.054	-.053	-0.059	.609

Notes: Coefficients statistically significant at the 1% level in bold. Coefficients statistically significant at the 5% level in italic.

Table A5: The factor representing regional universities—factor loadings and unique variances after varimax rotation

<i>Variable</i>	<i>Factor loading</i>	<i>Uniqueness</i>
Number of professors	0.9611	0.0762
Number of students	0.9358	0.1242
Number of graduates	0.9465	0.1041
Number of Ph.D. students	0.7909	0.3745
Amount of regular funds (1,000 €)	0.9116	0.1689
Amount of external funds (1,000 €)	0.9190	0.1554
Variance	0.9330	
Cronbach's alpha	0.9436	
<i>Note: All variables are logged.</i>		