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Does the Knowledge Spillover Theory of Entrepreneurship hold for regions?

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Abstract

The purpose of this paper is to test whether the Knowledge Spillover Theory of Entrepreneurship holds for regions. We do this by linking investments in knowledge by universities and regions to the amount of entrepreneurial activity associated with each university. Using binomial regressions we estimate how the number of young and high-tech firms located around universities depends on regional factors and the output of universities. The results clearly show that the number of firms located close to a university is positively influenced by the knowledge capacity of this region and the knowledge output of a university. Thus, there is considerable evidence suggesting that the Knowledge Spillover Theory of Entrepreneurship holds for regions as well as for industries.

Keywords: University spillover; Firm location

1. Introduction

As described by Audretsch and Thurik (2001), globalization is shifting the comparative advantage in the OECD countries away from being based on traditional inputs of production toward knowledge. As the comparative advantage has become increasingly based on new knowledge, public policy has responded enabling the creation and commercialization of knowledge. Furthermore, new policy approaches are emerging shifting the focus from national and international focuses towards regions and regional clusters. Examples of such policies include encouraging R&D spillovers, venture capital and new firm startups. In this new entrepreneurship based policy, universities play a key role in providing spillovers by academic research and human capital in the form of well trained and educated students. The success of a number of different technology clusters is the

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direct result of enabling policies, such as the provision of research support by universities.

The traditional view of knowledge and innovation is that the firm exists exogenously and then invests in research and development or the augmentation of human capital through training and education of workers to endogenously create new knowledge and ideas. This view was formalized by Griliches (1979) in what he termed as the Model of the Firm Knowledge Production Function.

While Griliches' model of the knowledge production function was statistically confirmed through a plethora of econometric studies linking knowledge inputs to innovative outputs at the levels of the country and the industry, the relationship proved to be considerably more ambiguous at the level of the firm, particularly when new and small enterprises were included in the sample. Small firms were found to contribute more to innovative output than would have been expected from their rather meager investments in R&D and other knowledge inputs.

This paradox of the high innovative output of small enterprises given their low level of knowledge inputs that seemingly contradicts the Griliches model of the firm knowledge production function was resolved by Audretsch (1995), who introduced the Knowledge Spillover Theory of Entrepreneurship, "The findings in this book challenge an assumption implicit to the knowledge production function—that firms exist exogenously and then endogenously seek out and apply knowledge inputs to generate innovative output. It is the knowledge in the possession of economic agents that is exogenous, and in an effort to appropriate the returns from that knowledge, the spillover of knowledge from its producing entity involves endogenously creating a new firm" (pp. 179–180).

What is the source of this entrepreneurial knowledge that endogenously generated the startup of new firms? The answer seemed to be through the spillover of knowledge from the source creating to commercialization via the startup of a new firm, "How are these small and frequently new firms able to generate innovative output when undertaking a generally negligible amount of investment into knowledge-generating inputs, such as R&D? One answer is apparently through exploiting knowledge created by expenditures on research in universities and on R&D in large corporations" (p. 179). While policy makers have no direct influence on large corporations as a source of spillovers, they can, more or less, influence universities as a promoter for entrepreneurship and important source of spillovers. As an example for Germany, the Federal Ministry for Education and Research established regions where startups from universities and government research laboratories are encouraged (Federal Ministry of Education and Research, 2004). Strongly influenced by federal and state policies, universities can alter their curricula, initiate research, and participate in collaborations that serve these ventures and thus allowing the startups to be more competitive with larger and better financed competitors.

The empirical evidence supporting the Knowledge Spillover Theory of Entrepreneurship was provided from analyzing variations in startup rates across different industries reflecting different underlying knowledge contexts. In particular, those industries with a greater investment in new knowledge also exhibited higher startup rates while those industries with less investment in new knowledge exhibited lower startup rates, which was interpreted as the mechanism by which knowledge spillovers are transmitted.

Thus, compelling evidence was provided suggesting that entrepreneurship is an endogenous response to the potential for commercializing knowledge that has not been adequately commercialized by the incumbent firms. This involved an organizational dimension involving the mechanism transmitting knowledge spillovers—the startup of new firms. In addition, Jaffe (1989), Audretsch and Feldman (1996) and Audretsch and Stephan (1996) provided evidence concerning the spatial dimension of knowledge spillovers. In particular their findings suggested that knowledge spillovers are geographically bounded and localized within spatial proximity to the knowledge source. None of these studies, however, identified the actual mechanisms which actually transmit the knowledge spillover; rather, the spillovers were implicitly assumed to automatically exist (or fall like Manna from heaven), but only within a geographically bounded spatial area.

The purpose of this paper is to bring these two literatures together by asking whether the Knowledge Spillover Theory of Entrepreneurship also has a spatial component in that the startups tend to cluster within geographic proximity to knowledge sources. The second section explains why the knowledge spillover theory should also have a spatial component in that the knowledge startups cluster geographically around the knowledge source. The third and fourth sections provide an empirical test within a spatial context—the region around a university. Finally, in the last section a summary and conclusion are provided. In particular, the empirical evidence suggests that those universities with a greater investment in knowledge and where the regional investment in knowledge is higher tend to generate more technology startups. This supports the view that the spillover theory of knowledge holds for regional contexts as well as for industries.

2. Localizing the Knowledge Spillover Theory of Entrepreneurship

That entrepreneurial activity varies across geographic space has long been observed. Efforts to systematically link spatial variations in entrepreneurship with locational specific characteristics showed that such spatial activity is not at all random but rather shaped by factors associated with particular regions (Reynolds et al., 1994). A series of studies, dating back at least to Carlton (1983) and Bartik (1985) and more recently Reynolds et al. (1994), have tried to identify characteristics specific to particular regions that account for inter-spatial variations in entrepreneurship. However, while a large literature exists linking new-firm startup activity to region-specific characteristics and attributes (Fritsch, 1997; Reynolds et al., 1994; Carlton, 1983; Bartik, 1985; Audretsch and Fritsch, 1994), virtually none of these studies provided a theory linking knowledge spillovers to new-firm startup activity, nor did any of these studies provide a measure of knowledge spillovers.

For example, Audretsch and Fritsch (1994), examine the impact that location plays on entrepreneurial activity in (West) Germany. Using a database derived from the social insurance statistics, which covers about 90% of employment, they identify the birth rates of new startups for each of 75 distinct economic regions. These regions are distinguished on the basis of planning regions, or *Raumordungsregionen*. They find that, for the late 1980s, the birth rates of new firms was higher in regions experiencing low unemployment, which have a dense population, a high growth rate of population, a high share of skilled workers, and a strong presence of small businesses.

The Knowledge Spillover Theory of Entrepreneurship provides a focus on the generation of entrepreneurial opportunities emanating from knowledge investments by incumbent firms and public research organizations which are not fully appropriated by those incumbent enterprises. It is a virtual consensus that entrepreneurship revolves around the recognition of opportunities and the pursuit of those opportunities (Shane and Eckhardt, 2003). Much of the more contemporary thinking about entrepreneurship has focused on the cognitive process by which individuals reach the decision to start a new firm. According to Sarasvathy et al. (2003, p. 142), “An entrepreurial opportunity consists of a set of ideas, beliefs and actions that enable the creation of future goods and services in the absence of current markets for them”. Sarasvathy, Dew, Velamuri and Venkataraman provide a typology of entrepreneurial opportunities as consisting of opportunity recognition, opportunity discovery and opportunity creation.

While much has been made about the key role played by the recognition of opportunities in the cognitive process underlying the decision to become an entrepreneur, relatively little has been written about the actual source of such entrepreneurial opportunities (see Audretsch and Stephan, 1999). The Knowledge Spillover Theory of Entrepreneurship identifies one source of entrepreneurial opportunities—new knowledge and ideas. In particular, the Knowledge Spillover Theory of Entrepreneurship posits that it is new knowledge and ideas created in one context but left uncommercialized or not vigorously pursued by the source actually creating those ideas, such as a research laboratory in a large corporation or research undertaken by a university, that serves as the source of knowledge generating entrepreneurial opportunities. Thus, in this view, one mechanism for recognizing new opportunities and actually implementing them by starting a new firm involves the spillover of knowledge. The source of the knowledge and ideas, and the organization actually making (at least some of) the investments to produce that knowledge, is not the same as the organization actually attempting to commercialize and appropriate the value of that knowledge—the new firm. If the use of that knowledge by the entrepreneur does not involve full payment to the firm making the investment that originally produced that knowledge, such as a license or royalty, then the entrepreneurial act of starting a new firm serves as a mechanism for knowledge spillovers. However, theories of localization suggest that just because universities are the sources of knowledge spillovers does not mean that knowledge transmits costlessly across geographic space. In particular, these theories argue that geographic proximity reduces the cost of accessing and absorbing knowledge spillovers. Thus, a basic tenet in the literature is that university spillovers lower the costs of firms to accessing and absorbing knowledge spillovers. If an entrepreneur decides to locate nearby a university, the benefits must outweigh the costs. Locating close to universities, mostly in the center of a city, is associated with high costs of living, housing, and others. Though, firms also have to pay higher wages to their employees since their costs of living. If the basic resources gathered from a university are not essential to bear those costs, it is more advantageous to locate outside such a metropolitan area.

There are at least two principle mechanisms facilitating the knowledge spillovers from universities to firms. The first one involves scientific research published in scholarly journals. Such published research is codified knowledge. This is because knowledge provided by articles can be transferred and transmitted with low cost, or with costs which are independent from the location. Academic papers can be downloaded from the Internet, obtained from publishers or found in libraries. However, an important qualification is that not all university knowledge is the same. In fact, the knowledge output of a university is heterogeneous. One useful distinction differentiates natural and social science knowledge. Social science knowledge is not based on a unified and established scientific methodology, but it rather is idiosyncratic to very specific disciplines, subdisciplines and even research approaches. Compared to the natural sciences, research in the social sciences is considerably less codified. Thus, geographic proximity to high output universities may be more important for accessing social science research than for accessing natural science research.

This suggests that an important testable hypothesis is that the amount of scientific articles published by a university has no effect on firm location, since accessing (codified) knowledge is more or less invariant to locational distance from the university producing that knowledge. Strict adherence to the scientific method assures that academic research embodies a high component of codified and specific knowledge in the natural sciences (Stephan, 1996). By contrast, the more limited applicability of the scientific method implies that research in the social sciences will embody less codified knowledge (Stephan, 1996). In contrast, academic research in the natural sciences is more codified. Because of its high codification, scientific knowledge can be largely accessed by (competently) reading scientific journals. Thus, we assume that knowledge in the social sciences is more tacit and less codified.

The second type of spillover mechanism involves human capital embodied in students graduating from the university. As Saxenien (1994) points out, one of the important mechanisms facilitating knowledge spillovers involves the mobility of human capital, embodied in graduating students, as they move from the university to a firm. Spatial proximity to universities can therefore generate positive externalities that can be accessed by the firm through the spillover mechanism of human capital. As Varga (2000) shows, university graduates may be one of the most important channels for disseminating knowledge from academia to the local high technology industry. In addition, other related externalities may result from close geographic proximity. For example, local proximity lowers the search costs for both firms and students. This may lead to some competitive advantage over similar firms which are not located close to universities, especially when high skilled labor is a scarce resource and there is intense competition about high potentials.

If a universities graduate's educational background correspondents to the needs of a firm, the probability of employment is higher which lowers the costs of matching for both students and firms. This contains to educate students and prepare them for later employment in the economy and academic research activities and thus provides spillovers. The business sector receives inputs from universities in the form of highly educated human capital. Although these individuals may require further training, university education provides the foundation for subsequent specialized industrial training. Universities may also provide further training of employees. Thus, it seems that the most frequent types of interactions between firms and universities are the employment of university graduates (Schartinger et al., 2001, p. 259).

Why should entrepreneurship play an important role in the spillover of new knowledge and ideas? And why should new knowledge play an important role in creating entrepreneurial opportunities? In the Romer (1986) model of endogenous growth new technological knowledge is assumed to automatically spill over. Investment in new technological knowledge is automatically accessed by third-party firms and economic agents, resulting in the automatic spill over of knowledge.[1] The assumption that knowledge automatically spills over is, of course, consistent with the important insight by Arrow (1962) that knowledge differs from the traditional factors of production – physical capital and (unskilled) labor – in that it is non-excludable and non-exhaustive. When the firm or economic agent uses the knowledge, it is neither exhausted nor can it be, in the absence of legal protection, precluded from use by third-party firms or other economic agents. Thus, in the spirit of the Romer model, drawing on the earlier insights about knowledge from Arrow, a large and vigorous literature has emerged obsessed with the links between intellectual property protection and the incentives for firms to invest in the creation of new knowledge through R&D and investments in human capital.

However, the preoccupation with the non-excludability and non-exhaustability of knowledge first identified by Arrow and later carried forward and assumed in the Romer model, neglects another key insight in the original Arrow (1962) article. Arrow also identified another dimension by which knowledge differs from the traditional factors of production. This other dimension involves the greater degree of uncertainty, higher extent of asymmetries, and greater cost of transacting new ideas. The expected value of any new idea is highly uncertain, and as Arrow pointed out, has a much greater variance than would be associated with the deployment of traditional factors of production. After all, there is relative certainty about what a standard piece of capital equipment can do, or what an (unskilled) worker can contribute to a mass-production assembly line. By contrast, Arrow emphasized that when it comes to innovation, there is uncertainty about whether the new product can be produced, how it can be produced, and whether sufficient demand for that visualized new product might actually materialize.

[1] For more recent models of endogenous growth combining both new economic geography models and R&D investments see Fujita and Thisse (2002, Chapter 11) or Baldwin and Forslid (2000).

In addition, new ideas are typically associated with considerable asymmetries. In order to evaluate a proposed new idea concerning a new biotechnology product, the decision maker might not only need to have a Ph.D. in biotechnology, but also a specialization in the exact scientific area. Such divergences in education, background and experience can result in a divergence in the expected value of a new project or the variance in outcomes anticipated from pursuing that new idea, both of which can lead to divergences in the recognition and evaluation of opportunities across economic agents and decision-making hierarchies. Such divergences in the valuation of new ideas will become greater if the new idea is not consistent with the core competence and technological trajectory of the incumbent firm.

Thus, because of the conditions inherent in knowledge – high uncertainty, asymmetries and transactions cost – decision making hierarchies can reach the decision not to pursue and try to commercialize new ideas that individual economic agents, or groups or teams of economic agents think are potentially valuable and should be pursued. The basic conditions characterizing new knowledge, combined with a broad spectrum of institutions, rules and regulations impose what Acs et al. (2003) term *the knowledge filter*. The knowledge filter is the gap between new knowledge and what Arrow (1962) referred to as economic knowledge or commercialized knowledge. The greater is the knowledge filter, the more pronounced is this gap between new knowledge and new economic, or commercialized, knowledge.

The knowledge filter is a consequence of the basic conditions inherent in new knowledge. Similarly, it is the knowledge filter that creates the opportunity for entrepreneurship in the Knowledge Spillover Theory of Entrepreneurship. According to this theory, opportunities for entrepreneurship are the duality of the knowledge filter. The higher is the knowledge filter, the greater are the divergences in the valuation of new ideas across economic agents and the decision-making hierarchies of incumbent firms. Entrepreneurial opportunities are generated not just by investments in new knowledge and ideas, but in the propensity for only a distinct subset of those opportunities to be fully pursued by incumbent firms.

Thus, the knowledge theory of entrepreneurship shifts the fundamental decision making unit of observation in the model of the knowledge production function away from exogenously assumed firms to individuals, such as scientists, engineers or other knowledge workers—agents with endowments of new economic knowledge. As Audretsch (1995) pointed out, when the lens is shifted away from the firm to the individual as the relevant unit of observation, the appropriability issue remains, but the question becomes, *How can economic agents with a given endowment of new knowledge best appropriate the returns from that knowledge?* If the scientist or engineer can pursue the new idea within the organizational structure of the firm developing the knowledge and appropriate roughly the expected value of that knowledge, he has no reason to leave the firm. On the other hand, if she places a greater value on his ideas than do the decision-making bureaucracy of the incumbent firm, he may choose to start a new firm to appropriate the value of his knowledge.

In the Knowledge Spillover Theory of Entrepreneurship the knowledge production function is actually reversed. The knowledge is exogenous and embodied in a worker. The firm is created endogenously in the worker's effort to appropriate the value of his knowledge through innovative activity. Typically an employee from an established large corporation, often a scientist or engineer working in a research laboratory, will have an idea for an invention and ultimately for an innovation. Accompanying this potential innovation is an expected net return from the new product. The inventor would expect to be compensated for his/her potential innovation accordingly. If the company has a different, presumably lower, valuation of the potential innovation, it may decide either not to pursue its development, or that it merits a lower level of compensation than that expected by the employee.

In either case, the employee will weigh the alternative of starting his/her own firm. If the gap in the expected return accruing from the potential innovation between the inventor and the corporate decision maker is sufficiently large, and if the cost of starting a new firm is sufficiently low, the employee may decide to leave the large corporation and establish a new enterprise. Since the knowledge was generated in the established corporation, the new start-up is considered to be a spin-off from the existing firm. Such startups typically do not have direct access to a large R&D laboratory. Rather, the entrepreneurial opportunity emanates from the knowledge and experience accrued from the R&D laboratories with their previous employers. Thus, the knowledge spillover view of entrepreneurship is actually a theory of endogenous entrepreneurship, where entrepreneurship is an endogenous response to opportunities created by investments in new knowledge that are not commercialized because of the knowledge filter.

As investments in new knowledge increase, entrepreneurial opportunities will also increase. Contexts where new knowledge plays an important role are associated with a greater degree of uncertainty and asymmetries across economic agents evaluating the potential value of new ideas. Thus, a context involving more new knowledge will also impose a greater divergence in the evaluation of that knowledge across economic agents, resulting in a greater variance in the outcome expected from commercializing those ideas (see Audretsch et al., 2006). It is this gap in the valuation of new ideas across economic agents, or between economic agents and decision-making hierarchies of incumbent enterprises, that creates the entrepreneurial opportunity.

As already discussed, a vigorous literature has already identified that knowledge spillovers are greater in the presence of knowledge investments. Just as Jaffe (1989) and Audretsch and Feldman (1996) show, those regions with high knowledge investments experience a high level of knowledge spillovers, and those regions with a low amount of knowledge investments experience a low level of knowledge spillovers, since there is less knowledge to be spilled over. Bode (2004) shows that in general interregional spillovers contribute significantly to regional knowledge production. Also Anselin et al. (1997) conclude that the geographical scope of knowledge spillovers is restricted to a limited number of neighboring regions or to regions within a given maximum distance from the region of interest.

The Knowledge Spillover Theory of Entrepreneurship analogously suggests that, ceteris paribus, entrepreneurial activity will tend to be greater in contexts where investments in new knowledge are relatively high, since the new firm will be started from knowledge that has spilled over from the source actually producing that new knowledge. A paucity of new ideas in an impoverished knowledge context will generate only limited entrepreneurial opportunities. By contrast, in a high knowledge context, new ideas will generate entrepreneurial opportunities by exploiting (potential) spillovers of that knowledge. Thus, the knowledge spillover view of entrepreneurship provides a clear link, or prediction that entrepreneurial activity will result from investments in new knowledge and that entrepreneurial activity will be spatially localized within close geographic proximity to the knowledge source.

3. Dataset, methodology, and descriptive statistics

To test the hypothesis that knowledge-based startups are located within close proximity to knowledge sources, we examine the spatial relation between knowledge-based startups and their proximity to universities. We do this by analyzing a unique dataset consisting of 281 firms which made an initial public offering (IPO) in Germany between March 1997 and March 2002. The dataset was collected combining individual data from IPO prospectuses, along with publicly available information from on-line data sources including the *Deutsche Boerse AG* (www.deutsche-boerse.com). We pooled this dataset by adding university-specific variables, which are individually collected from the 73 public universities in Germany (see Warning, 2004). The dependent variable is the number of firms located closest to a university (Firms). We do this by measuring the distance (in kilometers) between a firm and the surrounding universities. The distance is measured in kilometers using the online database of the *German Automobile Club* (www.adac.de). All firms located within a radius of 1.5 km are classified as belonging in the distance category of 1 km. Thus, the variable "Firms" contains all firms for which the distance towards this respective university is the closest one. No firm is allocated to more then one university.

To analyze the amount of knowledge investment that has been made by the university and elsewhere in the region, we include a measure that should reflect the potential supply of knowledge spillovers. This variable (regional capacity) is an index constructed by using spending in R&D and technological innovations in a specific region (see Sternberg and Litzenberger, 2003). This variable serves also as a measure for the "knowledge filter", which is significantly influenced by the structure of the innovation system within a regional context.

As university output we measure the number of students in the natural sciences (StudentsSCI) and in the social sciences as well as the articles published in the natural sciences (SCI) and the social sciences (SSCI). Information about the number of students is provided by the Federal Statistical Office. Since those data are provided sporadically we take 1997 as the base year where we have information of all universities. Publication data are hand-collected from the research database ISI (Information Sciences Institutes). We included the number of listed papers for each university published from 1993 until 2000.[2]

These measures are shown for the top 20 universities in Germany in Table 1. Using four distinct measures of university output enables us to examine any potential heterogeneous impact of university output.

We further include several control variables which may influence the degree of technology entrepreneurship located around a university. First, we include a dummy variable indicating a technical university (TU) (see Audretsch et al., in press). Technical universities are assumed to play a special role in the technology transfer, since their focus is especially on engineering and natural sciences (Audretsch and Lehmann, 2005). Those universities get more funds compared to other universities to foster and promote spillovers from new technologies to firms. Thus, technical universities may attract more young and high-tech firms. Secondly, we include the age (Age) of a university as measured in years to control for reputation effects. Thirdly, we use the number of inhabitants as the size of the city (City) of the respective university as well as the number of universities of applied sciences (universities). Those universities differ from the included public universities since their main goal is to educate students and are not engaged in academic research. They also do not have the status of a "university" in Germany. However, they also provide human capital and are thus included for this effect. Most of the included cities have a couple of such universities of applied sciences. Finally, a dummy variable is included to control for re-unification effects (West).

We employ the negative binomial regression model as the analytical technique for estimating the impact of the technology index and university research output on the role of geographic proximity. The underlying assumption is that the number of knowledge

[2] The publications in social science and natural science did not vary across the universities during time.

Table 1
List of the top 20 universities in Germany

University	Firms[a]	ϕ (km)[b]	SSCI Students[c]	SCI Students[d]
LMU München	51	17.9	43,633	8,119
Uni Frankfurt	26	19.5	26,324	5,715
Uni Hamburg	24	13.25	1,361	329
Uni Stuttgart	16	16.2	4,779	12,104
HU Berlin	14	7.78	20,769	4,936
Uni Köln	12	5.9	47,112	9,395
TU München	10	8.8	1,619	14,976
TU Karlsruhe	9	36.7	4,102	11,818
Uni Düsseldorf	7	18.57	14,697	4,762
Uni Erlangen-Nbg.	6	14	12,861	7,144
Uni Freiburg	6	40.33	12,334	4,942
FU Berlin	5	5.5	30,290	6,260
TU Aachen (RWTA)	5	3.4	7,884	20,570
Uni Jena	5	15.8	7,615	2,864
U-GH Paderborn	4	17	6,993	8,676
Uni Bielefeld	4	15.5	15,831	4,400
Uni Bremen	4	25.5	11,749	4,800
UdB München	4	14.25	1,054	1,104
Uni Kiel	4	40.75	13,000	6,513
Uni Regensburg	4	40	11,192	3,696

[a] Measured by the number of firms located closest to this university.
[b] ϕ (km) is the average distance of the firms located closest to this university.
[c] Number of students in the social sciences.
[d] Number of students in the natural sciences.

spillover startups located within geographic proximity to a university could be interpreted as count data. Since ordinary least squares regression is inappropriate for the count dependent variables that have large numbers of the smallest observation and remaining observations taking the form of small positive numbers, Poisson-regression seems to be more appropriate. However, the assumption for a Poisson-regression, the equality of mean and variance of the exogenous variable, is rejected by several tests. Thus, we apply the negative binomial regression model to overcome this problem of over-dispersion (Greene, 2003, pp. 740–752). Also, this statistical technique is designed for maximum likelihood estimation of the number of occurrence of nonnegative counts like the event of location.

In the first model (Model (1)), we estimate the following basic regression with the technology indices:

$$\begin{aligned}\text{Number of firms} &= \text{const.} + \beta_1 \text{regional technology capacity}\\ &\quad + \text{Controlvariables} + \varepsilon \qquad (1)\end{aligned}$$

Secondly, we test for the impact of university spillovers on the number of firms located to a university:

$$\begin{aligned}\text{Number of firms} &= \text{const.} + \beta_1 \text{StudentsSCI} + \beta_2 \text{StudentsSSCI}\\ &\quad + \beta_3 \text{SSCI} + \beta_4 \text{SCI} + \text{Controlvariables} + \varepsilon \qquad (2)\end{aligned}$$

then we test the combination from (1) and (2):

$$\begin{aligned}\text{Number of firms} &= \text{const.} + \beta_1 \text{regional capacity} + \beta_2 \text{StudentsSCI}\\ &\quad + \beta_4 \text{StudentsSSCI} + \beta_5 \text{SSCI}\\ &\quad + \beta_6 \text{Controlvariables} + \varepsilon \qquad (3)\end{aligned}$$

Finally, we estimate model (3) for selected industries. Our base hypotheses is that in models (1) and (3) $\beta_1 > 0$, that the numbers of firms clustered around a respective university depends on the regional capacity.

From the 73 public universities in Germany, only 54 universities are chosen as the closest university for the included firms. The descriptive statistics, as presented in Table 1, show the highly skewed number of firms located around universities. From the included 281 firms, 51 of them are located closest to the LMU Munich. The median distance of all firms located around the closest university is 7 km and the average distance is about 16 km. It could also be shown that the universities differ highly in their number of students in the natural sciences and the social sciences (see Warning, 2004, for more details).

4. Empirical evidence

In this section, we provide the results of the negative binomial regressions with the number of firms clustered around a university as the dependent variable. The empirical results for the negative binomial regression equations estimating the number of knowledgebased-startups located within geographic proximity to each university are presented in Table 2. The dependent variable is the number of firms located within geographic proximity to a university. As explained in the previous section, the first model includes only the technology index, the second model includes only the measures of university outputs, and the third model includes both types of measures.

In the first model, as the positive and statistically significant coefficient of the measure of technology capacity of the region in which the university is located suggests, the greater the technological capacity of the region, the greater are the number of firms locating in that region.

The negative coefficient of university age does not support the hypothesis that university reputation, at least measured by age, has a positive influence on startups. Rather, the younger a university is, the more firms tend to locate with close geographic proximity. This finding could be explained by the fact that old and traditional universities are more focused on the social sciences, resources which are not really necessary for young and high-tech firms. The same holds for technical oriented universities which are mainly focused on the traditional research in engineering and machineries. While the size of the city is insignificant, the number of firms is also explained by the number of universities.

The results of the second estimation model show that university output influences the location decision of firms. As found by others (Schartinger et al., 2001; Stephan, 2001) the amount of university educated human capital is one of the major factors influencing firm location. Proximity offers the possibility of linking students to industry more efficiently, by providing industry and students a pre-employment look at each other. Thus, universities with a high output of students tend to generate more knowledge-based startups.

New technology oriented firms are particularly dependent on technological innovations and scientific progress and are therefore more than others

Table 2
Negative binomial estimating regional technology startups

	Model I	Model II	Model III
Regional knowledge capacity	0.03753 (10.19)***		0.4279 (16.95)***
SCI students		0.0004 (3.77)***	0.0001 (1.36)
SSCI students		0.00003 (10.03)***	0.0003 (14.36)***
SSCI		−0.0009 (8.43)***	−0.0009 (11.06)***
SCI		0.1100 (3.13)***	0.1149 (3.99)***
Age	−0.0004 (2.27)**		
	0.0005 (2.30)**	−0.00057 (2.90)**	
TU	−1.4786 (10.20)***	−1.1976 (6.65)***	−1.389 (9.53)***
City	−1.17E07 (1.10)	−0.856E07 (10.09)***	−3.06E07 (3.96)***
Universities and universities of applied sciences	0.4047 (6.24)***	1.1935 (20.90)***	0.681 (12.90)***
West	−0.2029 (0.93)	−0.6351 (3.32)***	−0.5320 (3.61)***
Const.	0.4892 (1.65)*	1.7352 (6.65)***	0.6887 (3.07)***
Pseudo R2	0.1792	0.2067	0.3412
LL-ratio	−897.76	−850.11	−705.998

The endogenous variable is the number of technology startups located within geographic proximity to a university. *Z*-values are in brackets. The asterisks, *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. The dataset includes 281 firms and 54 universities.

inclined to engage in interactions with research intense universities. Thus, research intense universities especially in the natural sciences are more attractive for high-tech firms. This could be confirmed by the positive significance of the coefficient indicating the number of articles published in the natural sciences. However, research intensity in the social sciences seems to be less important for attracting high-tech firms.

The third regression model includes both the regional innovation capacity measures and the university output measures and is consistent with the previous results, indicating that the results are robust. The number of new knowledge-based firms located within close geographic proximity to a university is positively influenced by the knowledge output of the respective university and the innovative capacity of the region. In both regressions, the dummy variable controlling for the reunification effect is significant negative for West Germany. This could be explained by the entrepreneurial policy which is concentrated around universities in East Germany, especially Dresden in Saxony and Thüringen (see Acs, 2002, p. 190).

This third model is also estimated for major technology industries or groups. As the results in Table 3 suggest, the evidence suggests that not all of the knowledge measures have a homogeneous impact on entrepreneurship across the particular industries. The results show that the demand for high skilled labor, as expressed by the number of students, differs across the industries. Especially in the high-technology and knowledge intense industries, the amount of students in the natural sciences enters the regressions significantly. While research activities in the social sciences seem to have no impact on the number of firms clustered around a university, the results differ for research in the natural sciences. The number of articles published in this field is significant and positive in the Hardware and Technology sector as well as in the Biotechnology and Medicine Technique sector. This strongly supports the thesis that university research in those fields can provide knowledge spillovers in high-technology and knowledge based industries.

Thus, there is no reason to think that knowledge spillover entrepreneurship is invariant to the type of knowledge or the industry context. Still, these results confirm that there is compelling evidence suggesting that knowledge-based startups tend to cluster within geographic proximity to the knowledge source.

Table 3
Negative binomial estimating regional technololgy startups

	Software	Service	Media and Entertainment	Hardware/technology	Biotec/medtec
Regional capacity	0.0437 (7.59)***	0.0402 (7.81)***	0.04377 (4.50)***	0.06128 (8.08)***	0.0706 (2.36)**
SCI students	−1.50E06 (0.09)	0.0001 (0.98)	0.0001 (2.30)***	0.0002 (2.59)***	0.0003 (3.04)***
SSCI students	0.00002 (3.17)***	0.0003 (8.84)***	0.0004 (3.35)***	0.0004 (4.49)***	0.0006 (3.69)***
SSCI	−0.001 (1.13)	−0.012 (1.39)	−0.001 (1.13)	−0.0005 (1.52)	−0.0018 (1.35)
SCI	−0.1971 (0.92)	0.2076 (0.71)	−0.0043 (0.08)	0.2356 (2.05)**	0.0103 (1.67)*
Age	0.00002 (0.05)	−0.0004 (1.16)	−0.006 (1.12)	−0.003 (2.96)***	0.0025 (0.85)
TU	−1.0577 (3.46)***	−0.9135 (3.15)***	−2.284 (3.01)***	−0.5618 (1.59)	1.468 (1.67)*
City	−0.282E07 (5.34)***	−4.74E07 (2.85)***	−3.45E07 (1.48)	−1.17E07 (0.24)	−1.18E06 (1.47)
West	−0.4105 (1.01)	−0.5606 (1.67)*	−0.4876 (1.12)	−0.7883 (0.88)	−3.130 (1.45)
Number of universities	0.8234 (5.34)***	0.9007 (7.66)***	0.7666 (3.42)***	0.4493 (1.26)	0.7164 (1.72)*
Const.	0.3309 (0.62)	0.7129 (1.41)	0.3122 (0.23)	0.2576 (0.22)	3.5109 (2.12)*
Pseudo R2	0.3722	0.3560	0.4042	0.3999	0.4143
LL-ratio test (χ^2)	−130.485	−164.059	−93.357	−110.326	−51.769
Number of firms in each industry	55	67	37	47	25

The endogenous variable is the number of technology startups located within geographic proximity to a university. *Z*-values are in brackets. The asterisks, *, **, and *** indicate significance at the 10%, 5%, and 1% level, respectively. $N = 54$ universities. We dropped all industries with less than 20 firms and matched Hardware and Technology as well as Biotech and Medtec to increase the number of firms in the regressions.

5. Conclusion

The Knowledge Spillover Theory of Entrepreneurship suggests that investment in the creation of new knowledge will generate opportunities for entrepreneurship as a mechanism for knowledge spillovers. While empirical evidence has already been provided supporting the Knowledge Spillover Theory of Entrepreneurship for the different contexts provided by industry specific knowledge investments, little was known about the spatial dimension. This paper has found that those universities in regions with a higher knowledge capacity and greater knowledge output also generate a higher number of technology startups. Thus, at least on the basis of data from Germany, there is considerable evidence that the Knowledge Spillover Theory of Entrepreneurship holds for regions as well as for industries.

As comparative advantage has become increasingly based on new knowledge, the results show that public policy can respond in two fundamental ways. First, by providing an infrastructure that enables young firms to absorb necessary resources. This is shown by the positive effect of the regional knowledge capacity on firm location. Secondly, by influencing universities to increase their research activities, especially in the natural sciences and in providing well educated students.

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References

Acs, Z., 2002. Innovation and the Growth of Cities. Edward Elgar, Cheltenham.

Acs, Z., Audretsch, D.B., Braunerjhelm, P., Carlsson, B., 2003. The Missing Link: The Knowledge Filter and Endodenous Growth. Center for Business and Policy Studies, Stockholm, Sweden.

Anselin, L., Varga, A., Acs, Z., 1997. Local geographic spillovers between university research and high technology innovations. Journal of Urban Economics 42, 422–448.

Arrow, K., 1962. Economic welfare and the allocation of resources for invention. In: Nelson, R. (Ed.), The Rate and Direction of Inventive Activity. Princeton University Press, Princeton.

Audretsch, D.B., 1995. Innovation and Industry Evolution. MIT Press, Cambridge/Mass.

Audretsch, D.B., Lehmann, E.E., 2005. Mansfields's missing link: the impact of knowledge spillovers on firm growth. Journal of Technology Transfer 30 (1/2), 207–210.

Audretsch, D.B., Keilbach, M., Lehmann, E.E., 2006. Entrepreneurship and Growth. Oxford University Press, in press.

Audretsch, D.B., Feldman, M.P., 1996. R&D spillovers and the geography of innovation and production. American Economic Review 86, 630–640.

Audretsch, D.B., Fritsch, M., 1994. The geography of firm births in Germany. Regional Studies 28 (4), 359–365.

Audretsch, D.B., Stephan, P.E., 1996. Company-scientist locational links: the case of biotechnology. American Economic Review 86 (3), 641–652.

Audretsch, D.B., Stephan, P.E., 1999. How and why does knowledge spill overs in biotechnology? In: Audretsch, D.B., Thurik, R. (Eds.), Innovation, Industry Evolution, and Employment. Cambridge University press, Cambridge, pp. 216–229.

Audretsch, D.B., Thurik, R., 2001. What is new about the new economy: sources of growth in the managed and entrepreneurial economies. Industrial and Corporate Change 19, 795–821.

Baldwin, R.E., Forslid, R., 2000. The core-periphery model and endogenous growth: stabilizing and destabilazing integration. Economics 67, 307–324.

Bartik, T., 1985. Business location decisions in the United States: estimates of the effects of unionization, taxes, and other characteristics of the states. Journal of Business and Economic Statistics 3 (January), 16–22.

Bode, E., 2004. The spatial pattern of localized R&D spillovers: an empirical investigation for Germany. Journal of Economic Geography 4, 43–64.

Carlton, D.W., 1983. The location and employment choices of new firms: an econometric model with discrete and continuous endogenous variables. Review of Economics and Statistics 65 (3), 440–449.

Federal Ministry of Education and Research, 2004. Facts and Figures 2002 (http://www.bmbf.de).

Fritsch, M., 1997. New firms and regional employment change. Small Business Economics 9 (5), 437–448.

Fujita, M., Thisse, J.-F., 2002. Economics of Agglomeration. Cities, Industrial Location, and Regional Growth. Cambridge University Press, Cambridge.

Greene, W.H., 2003. Econometric Analysis, fifth ed. Prentice Hall, New York.

Griliches, Z., 1979. Issues in assessing the contribution of research and development to productivity growth. Bell Journal of Economics 10, 92–116.

Jaffe, A.B., 1989. Real effects of academic research. American Economic Review 79, 957–970.

Reynolds, P., Storey, D.J., Westhead, P., 1994. Cross-national comparisons of the variation in new firm formation rates. Regional Studies 28 (4), 443–456, July.

Romer, P.M., 1986. Increasing returns and long-run growth. Journal of Political Economy 94, 1002–1037.

Sarasvathy, S.D., Dew, N., Ramakrishna Velamuri, S., Venkataraman, S., 2003. Three views of entrepreneurial opportunity. In: Acs, Z., Audretsch, D.B. (Eds.), Handbook of Entrepreneurship Research. Kluwer Academic Publishers, Dordrecht, pp. 141–160.

Saxenien, A., 1994. Regional Advantage: Culture and Competition in Silicon Valley and Route 128. Harvard University Press, Cambridge, MA.

Schartinger, D., Schibany, A., Gassler, H., 2001. Interactive relations between universities and firms: empirical evidence for Austria. Journal of Technology Transfer 26 (3), 255–268.

Shane, S., Eckhardt, J., 2003. The individual-opportunity nexus. In: Acs, Zoltan J., Audretsch, D.B. (Eds.), Handbook of Entrepreneurship Research. Kluwer Academic Publishers, Dordrecht, pp. 161–194.

Stephan, P., 1996. The economics of science. Journal of Economic Literature 34 (3), 1199–1235.

Stephan, P., 2001. Educational implications of university-industry technology transfer. Journal of Technology Transfer 26 (3), 199–205.

Sternberg, V.R., Litzenberger, T., 2003. Regional clusters—operationalisation and consequences for entrepreneurship. Working paper, University of Cologne.

Varga, A., 2000. Local academic knowledge transfers and the concentration of economic activity. Journal of Regional Science 40, 289–309.

Warning, S., 2004. Performance differences in the German Higher Education System: empirical analysis of strategic groups. Review of Industrial Organization 24, 393–408.