Chapter 7
The Role of Knowledge

7.1 Regional Knowledge and Entrepreneurship

Knowledge is a key source for start-ups, particularly in innovative industries (Acs et al. 2009, 2013; Fritsch 2011; Fritsch and Aamoucke 2013, 2017). Accordingly, new businesses in general, and innovative start-ups in particular, can be regarded as manifestations of knowledge spillovers from extant knowledge sources (Acs et al. 2009, 2013). There are at least two reasons to expect that geographic proximity plays an important role in the process of entrepreneurial knowledge spillovers. First, new knowledge does not flow freely across space, but tends to be regionally bounded (Anselin et al. 1997; Asheim and Gertler 2006; Boschma 2005). Second, founders have a pronounced tendency to locate their firms in close spatial proximity to their former workplace, or near where they reside (Figueiredo et al. 2002; Dahl and Sorenson 2009). Hence, the regional knowledge stock, the regional workforce, and the regional conditions for entrepreneurship are all important factors in the emergence of innovative new businesses.

While a number of studies have shown the importance of regional knowledge for innovative start-ups (Audretsch et al. 2005; Fritsch and Aamoucke 2013, 2017), the historical roots of the current knowledge base and their role for innovative entrepreneurship have remained largely unexplored.[1] Clearly, knowledge does not suddenly fall on regions 'from heaven', but emerges and develops over longer periods of time shaping types of regional activity and industry structures.

This chapter is based on Fritsch and Wyrwich (2018).

[1]For an overview of studies that find long-term persistence of entrepreneurship, see Fritsch and Wyrwich (2017b). Most studies that investigate the sources of regional knowledge and entrepreneurship (e.g., Grabher 1993; Saxenian 1994, and the contributions in Braunerhjelm and Feldman 2006) are on a case-study basis so that the results can hardly be generalized. Recent quantitative approaches based on larger sets of regions analyze the evolution of industries and industrial path-dependencies in regions in the medium run (e.g., Klepper 2009; Boschma 2017).

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We investigate the extent to which a historical tradition of entrepreneurship and the historical knowledge base of a region contribute to new business formation in innovative industries today. We focus on innovative entrepreneurship for two reasons. First, there is good reason to assume that innovative entry that exerts fierce competitive pressure on incumbents is particularly important for stimulating regional growth (Fritsch 2011). Second, the knowledge intensity inherent in innovative new businesses makes them a well-suited source for analyzing the role of regional knowledge for entrepreneurship. The aim of this study is to gain a better understanding of the historical roots of contemporaneous regional differences in innovative entrepreneurship. We want to contribute to answering the following question: "Why do some regions have better prospects of gaining from knowledge-based developments than others?" Based on the knowledge spillover theory of entrepreneurship (Acs et al. 2009, 2013), we hypothesize that there is a stronger persistence of innovative entrepreneurship in regions that had a relatively large knowledge base and high levels of self-employment in science-based industries at the outset of the twentieth century.

In Sect. 7.2, we briefly survey the literature dealing with the role of regional knowledge and an entrepreneurial tradition of entrepreneurship. Section 7.3 introduces our measures of the historical knowledge base and gives an overview of the spatial distribution of innovative start-ups. The results of the empirical analyses of the effects of historical knowledge and entrepreneurship on the formation of innovative new businesses today are presented in Sect. 7.4. Section 7.5 discusses these results, concludes and draws implications for policy and for further research.

7.2 The Role of History: Knowledge Trajectories and Entrepreneurial Tradition

The basic idea of the knowledge spillover theory of entrepreneurship (Acs et al. 2009, 2013) is that knowledge, particularly new knowledge, is an important source of entrepreneurial opportunities. For this reason, a large and dynamically growing knowledge base should have the potential to provide rich opportunities for many start-ups. This should be especially true for innovative new businesses as they are particularly dependent on knowledge inputs. Consistent with these considerations, research has documented a pronounced relationship between indicators of regional knowledge and new business formation (particularly with start-ups in innovative and knowledge-intensive industries), such as the presence of academic institutions and the level of R&D activities (Audretsch et al. 2005; Fritsch and Aamoucke 2013, 2017).

Since a larger part of the available knowledge is tacit, it is attached to people and, therefore, regionally bounded. Due to this stickiness of tacit knowledge, it tends to remain in the local population and is transferred across generations. This characteristic, as well as the continuity of well-established institutions of higher education and research (such as universities), influences the persistence and scope of regional knowledge levels and knowledge profiles over longer periods of time. Hence, there are significant differences in the amount and character of the available knowledge across regions.

The knowledge spillover theory of entrepreneurship (Acs et al. 2009, 2013) argues that a rich regional knowledge base does not automatically give rise to new businesses, but that entrepreneurial people who recognize and seize the available opportunities are also required.[2] Hence, the propensity of the regional population to start a venture is important for entrepreneurial spillovers to occur. Empirical studies have identified a number of factors that appear to be conducive to entrepreneurial behavior, such as qualification of the workforce, employment in small businesses (e.g., Chinitz 1961; Parker 2009) and personality traits of the regional population (Stuetzer et al. 2017; see Chap. 8). Research has particularly highlighted the role of social acceptance of entrepreneurial behavior (Etzioni 1987; Kibler et al. 2014), or a regional entrepreneurship culture (Beugelsdijk 2007; Fritsch and Wyrwich 2014, 2017b). Chinitz (1961) argues that an entrepreneurial culture is more likely to emerge in areas with high employment shares in small businesses. This argument is further developed in Stuetzer et al. (2016). In a nutshell, workers in small firms are in closer contact with an entrepreneurial role model and can acquire entrepreneurial skills more easily than workers in large firms. Such role model effects may trigger a positive perception of entrepreneurship and hence stimulate a personal decision to start a firm.[3]

Analyzing the role of history for new business formation in innovative industries today, we combine measures of historical entrepreneurship with indicators of regional industry structures, combined with information on the presence of universities. In particular, we investigate whether these factors are complementary in their effect on current new business formation. Our data suggests that, not only regional differences in entrepreneurship, but also regional differences of the knowledge stock and the level of knowledge generation tend to be rather persistent over time. Our main hypothesis is that it is not the historical knowledge base, per se, but it is the interaction of this knowledge base with an entrepreneurial tradition that has an enduring effect on the formation of innovative new businesses today.

[2] Saxenian's (1994) comparison of the computer industry in Silicon Valley and the East Coast provides an impressive example of the role of entrepreneurship for the successful commercialization of knowledge.

[3] Based on an empirical analysis of the development of the German Ruhr area, which is dominated by large-scale industries, Grabher (1993) argues that the old established incumbents may show a tendency to suppress the emergence of novel ideas and entrepreneurship.

7.3 Historical Regional Knowledge

Our main indicators for the historical regional knowledge base are the presence of higher education institutions in the early twentieth century and, alternatively, the minimum distance of regions to a higher education institution. We distinguish between ‘classical’ universities and technical universities and form two binary variables for the presence of a classical university or a technical university in the region before the year 1900.[4] The idea behind the distance measures is that knowledge spillovers are found to be highly localized and sticky (Anselin et al. 1997; Fritsch and Aamoucke 2013). Thus, the spillover effects of technical universities and classical universities should decay with increasing geographic distance. A further advantage of the distance measure is that it rules out that the spillover effect is driven by the low number of regions with technical universities and classical universities, as indicated by the binary variables.

Technical universities in Germany began to emerge in the mid-nineteenth century. In contrast to classical universities, they had a focus on natural sciences and engineering, and were much more oriented towards the commercial application of knowledge (Drucker 1998, p. 21). While it was rather unusual for German classical universities at that time to have cooperative links with private firms, the pronounced collaboration of technical universities with the private sector could have made the figure of the entrepreneur more legitimate in regions hosting a technical university and may in this way have been conducive to higher levels of self-employment. Table 7.1 provides an overview of the universities founded prior to 1900.

All technical universities in Germany that existed in the year 1900 emerged from technical colleges (*Polytechnische Hochschulen*) that were founded earlier in the nineteenth century as a reaction to the rapidly growing general demand for scientific research and education (Drucker 1998; Carlsson et al. 2009). The main political force behind the upgrading of technical colleges to technical universities was the German Association of Engineers (*Verband Deutscher Ingenieure*, VDI).[5] All technical colleges that became technical universities before 1900 were located in the capital cities of the Federal States (for details see König 2006; Manegold 1989). There is no indication that they were strategically placed primarily in regions with high levels of self-employment. Today, technical universities in Germany represent just one specific type of higher education institution that has relatively strong links to private sector firms.

[4]There were three classical universities founded between 1900 and 1925 (University of Frankfurt/M. in 1914, University of Cologne in 1919 and University of Hamburg in 1919). These university foundings are not considered in order to keep the indicator consistent for the years 1907 and 1925.

[5]A main aim of the initiatives to upgrade technical colleges was to overcome the lower social status of engineers as compared to university graduates. Moreover, upgrading technical colleges to technical universities was regarded an important means for improving the education of engineers (see König 2006).

Table 7.1 List of universities in Germany founded prior to the year 1900

Type of higher education institution	Size (number of students 1911)	Type of higher education institution	Size (number of students 1911)
Classical universities		*Classical universities*	
Berlin	7.585	Gießen	1.315
Munich	6.942	Greifswald	1.165
Leipzig	4.088	Erlangen	1.104
Bonn	3.805	Rostock	9.20
Freiburg	3.080	*Technical universities*	
Goettingen	2.476	Munich	2.376
Heidelberg	2.452	Berlin	1.959
Marburg	2.240	Darmstadt	1.231
Halle	2.209	Karlsruhe	1.052
Kiel	2.063	Dresden	1.022
Tuebingen	1.979	Hannover	8.36
Muenster	1.969	Stuttgart	5.80
Jena	1.902	Aachen	5.57
Wuerzburg	1.449	Brunswick	3.70

Notes: The planning region Mittelhessen hosts two classical universities (Marburg and Gießen). Based on the sum of students the planning region is counted as hosting a large classical university in the analysis

Source: Deutsche Hochschulstatistik (1929)

There are at least three reasons why the presence of higher education institutions in the early twentieth century is a meaningful indicator of the historical knowledge base. First, universities play an important role for the absorption, storage and diffusion of knowledge, and they are also engaged in the generation of new knowledge. Second, they provide innovation-related inputs and contribute to the regional stock of human capital (Schubert and Kroll 2016) that plays an important role for identifying entrepreneurial opportunities. Third, universities are key actors—brokers and gatekeepers—in local innovation systems (e.g., Graf 2011; Kauffeld-Monz and Fritsch 2013). Thus, we believe that the presence of a university fairly captures differences in the regional knowledge base and the quality of human capital as compared to regions that do not have higher education institutions.[6]

We construct measures of science-based entrepreneurship in the years 1907 and 1925 (for details, see Chap. 3). For 1925, this is the number of self-employed in: machine, apparatus, and vehicle construction, electrical engineering, precision mechanics, optics, chemicals and rubber and asbestos. These industries are regarded as science-based and knowledge-intensive. Individuals self-employed in these industries in 1925 constitute 3.23% of all the self-employed. For the empirical analysis, the number of self-

[6]At the same time, we agree that there could have been differences in the quality of universities in the early twentieth century which we cannot measure. Please note that there is no regional variation in literacy levels in Germany between 1907 and 1925, since schooling was compulsory.

employed is divided by the total number of employees in the region. The industry classifications used in 1907 differ from and are less detailed then those used in 1925. For 1907, we classify machine construction and instruments as well as chemical industries as science-based, and divide the number of establishments in these industries by the total number of employees. The share of establishments in these industries is 3.27%.

Figure 7.1 shows the spatial distribution of the self-employment rate in science-based industries in the years 1907 and 1925, as well as the distribution of classical and technical universities. In both years, we find relatively high levels of self-employment in science-based industries in the southwest (Baden-Wuerttemberg), and in some regions in the east, particularly to the southwest of Berlin. The relatively low self-employment rates in the Ruhr area north of Cologne, a region that was dominated by large-scale industries for a long time, is also noteworthy. Most of the relatively few technical universities were located in regions with high levels of self-employment in science-based industries. This pattern is more pronounced in 1925.

Figure 7.2 shows the average start-up rates in technology-intensive industries during 2000–2016 (for details on start-up data, see Chap. 3) in accordance to the definition by Gehrke et al. (2010). We again find relatively high rates in the southwest of the country. High levels of new business formation in technology-intensive industries can also be found around Hamburg and, again, to the southwest of Berlin. There is a remarkable correspondence of the presence of a technical university in the year 1900 and current rates of innovative new business formation. Table 7.5 in the Appendix lists the definitions of the variables used in the analysis, and Table 7.6 presents summary statistics for these variables.[7]

7.4 Results

7.4.1 Persistence of Regional Knowledge

In a first step of our analysis we investigate the persistence of regional knowledge. A first indication of the persistence of regional knowledge intensity is that all of the universities that were present in 1900 still exist today. To further explore the persistence of regional knowledge we regress the information on the presence of a university in the year 1900 on two indicators for innovation activity today: the number of patents per person employed,[8] and the employment share of R&D employees.[9] Population density in the year 1907 is included as a "catch-all" variable

[7]For a correlation matrix, see Fritsch and Wyrwich (2018, Table A2).

[8]Patents (per 10,000 working population) are taken from the REGPAT data base, and are assigned to the region where the inventor has his or her residence. If a patent has more than one inventor, the count is divided by the number of inventors and each inventor is assigned his or her share of that patent.

[9]Data on the share of R&D employees is from the German Employment Statistics, which covers all employees subject to compulsory social insurance contributions (Spengler 2008). R&D employees are defined as those with tertiary degrees working as engineers or natural scientists.

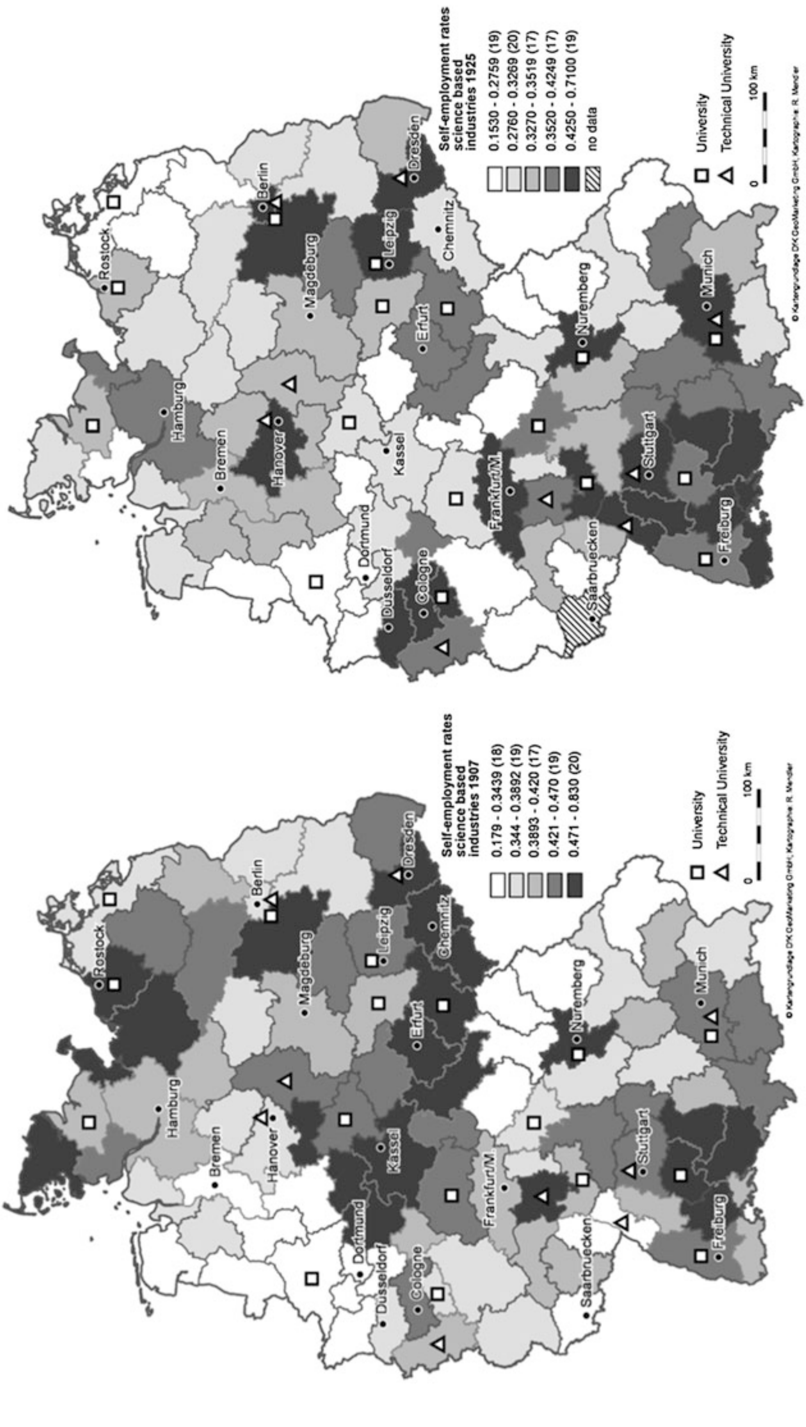

Fig. 7.1 Spatial distribution of the self-employment rate in science-based industries of the economy in the years 1907 (left) and 1925 (right)

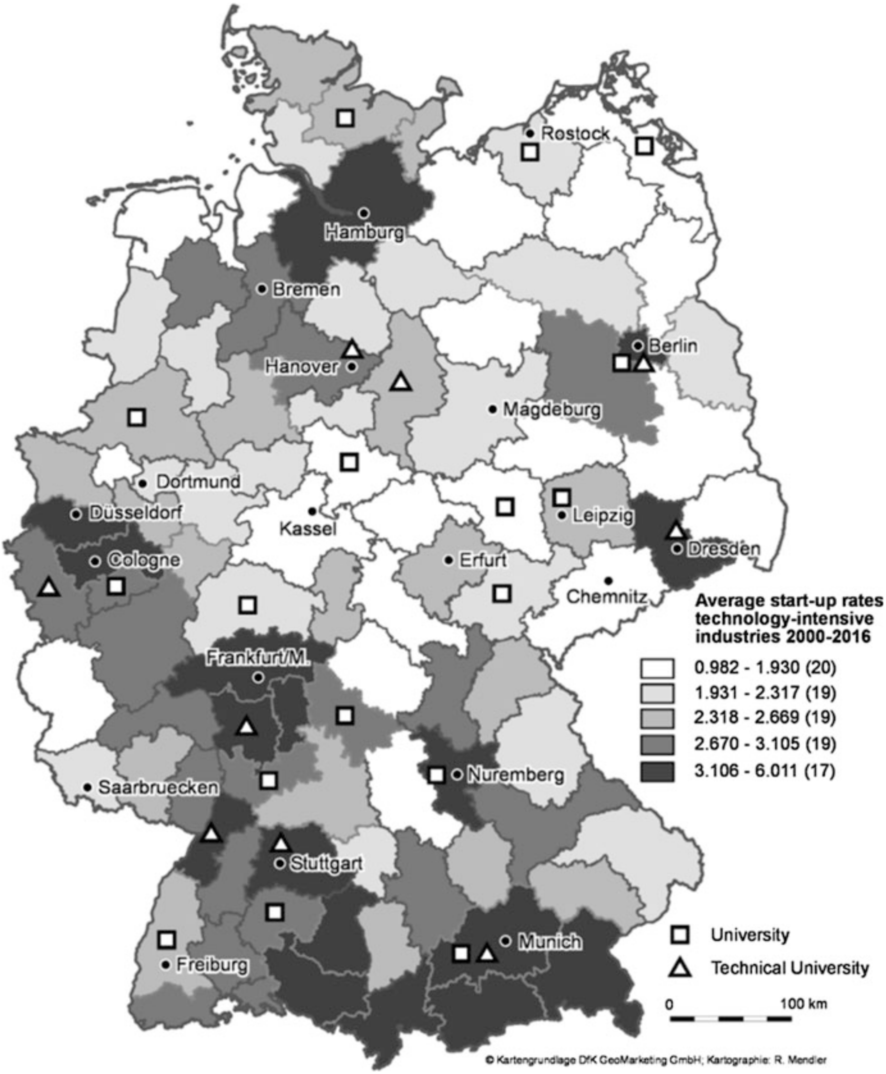

Fig. 7.2 Average yearly start-up rates in Germany 2000–2016 technology-intensive industries

that controls agglomeration effects and general economic conditions such as wage level, house prices, etc. Dummy variables for the Federal States are intended to capture differences in state-level policies that may affect entrepreneurship. We also include the employment share in manufacturing in the year 1907 to control for the effects of the regional industry structure. The distance to the nearest coalfield is intended to control for effects of natural resource endowments.[10] Since all continuous

[10]The coalfields considered are those in the Ruhr area, the Saarland, and the Middle German field (Halle-Leipzig) (see Châtel and Dollfus 1931).

variables are logged, the respective coefficients can be interpreted as elasticities that indicate the relative importance of the respective measure.

We find that both indicators for the historical knowledge base (the presence of a classical university and/or of a technical university) are highly significant (Table 7.2). The coefficients for the presence of a technical university are much larger than those for the presence of a classical university, suggesting a relatively strong effect of a regional tradition in natural sciences and engineering. The estimated coefficients indicate that regions with a technical university have 81% more patents per working population today than regions without any university (Model I in Table 7.2). For classical universities this effect is about 36%. The presence of a technical university increases the employment share of R&D employees by 57%, while the presence of a classical university increases this share by 25% compared to regions without a classical university or technical university (Model III in Table 7.2). The estimates also clearly suggest (Models II and IV in Table 7.2) that geographic proximity to classical universities and technical universities matters. A 1% increase in the distance from a classical university reduces the patenting rate by 0.1%, while a 1% increase in the distance from a technical university is associated with a drop of 0.2%. The effects are slightly smaller for the employment share of R&D employees (0.06% for classical universities; 0.13% for technical universities). The results are robust when considering regional control variables for the year 1925 instead of 1907 (Table 7.2, Models V, VI, VII and VIII). These results clearly demonstrate a pronounced persistence of regional knowledge intensity over rather long periods of time. In an additional analysis, we distinguished between large and small classical universities and technical universities in terms of the number of students registered in 1911.[11] We split the data at the median value, which implies that classical universities with less than 2000 students are marked as small, while the respective threshold for technical universities is 1000 students. The results indicate that the effects of historical knowledge on today's innovation activities are stronger for larger classical and technical universities.[12]

7.4.2 Persistence of Entrepreneurship

Table 7.3 shows the main results of our analysis of the effects of historical knowledge and historical self-employment rates on regional levels on new business formation in innovative industries. We do not consider indicators of modern day regional entrepreneurship and knowledge because these measures are probably

[11]This information is available from historical university statistics (Deutsche Hochschulstatistik 1929).

[12]Due to the rather small number of observations, one should not over interpret the results of the distinction made between small/large universities. The classification of universities by size is provided in Table A1 in Fritsch and Wyrwich (2018). The results of the empirical analysis are shown in Table A3 of the respective article.

Table 7.2 Persistence of regional knowledge

	I	II	III	IV	V	VI	VII	VIII
	Controls 1907				Controls 1925			
Dependent variable	Patents per working age population		Employment share of R&D employees		Patents per working age population		Employment share of R&D employees	
Distance to university founded before 1900	−0.098***		−0.063***		−0.100***		−0.064***	
	(0.033)		(0.013)		(0.033)		(0.013)	
Distance to technical university founded before 1900	−0.203***		−0.135***		−0.206***		−0.137***	
	(0.054)		(0.014)		(0.054)		(0.015)	
University founded before 1900 (Yes = 1)		0.367**		0.245***		0.015		0.257***
		(0.146)		(0.056)		(0.138)		(0.054)
Technical university founded before 1900 (Yes = 1)		0.801***		0.578***		−0.004		0.591***
		(0.255)		(0.068)		(0.069)		(0.070)
Population density	−0.062	−0.0316	0.163***	0.176***	−0.0124	0.762***	0.164***	0.175***
	(0.138)	(0.146)	(0.044)	(0.049)	(0.131)	(0.245)	(0.045)	(0.051)
Distance to nearest coalfield	−0.018	−0.030	0.042**	0.0351	0.007	0.386**	0.055**	0.049**
	(0.068)	(0.070)	(0.020)	(0.024)	(0.067)	(0.149)	(0.022)	(0.025)
Employment share in manufacturing	0.828***	0.909***	0.370**	0.415***	0.690***	0.822***	0.351***	0.392***
	(0.277)	(0.297)	(0.142)	(0.146)	(0.229)	(0.258)	(0.109)	(0.116)
Federal State dummies	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Constant	−1.490	−3.325***	−5.988***	−7.142***	−0.972	−2.763***	−5.809***	−6.948***
	(1.230)	(1.157)	(0.545)	(0.552)	(1.087)	(1.018)	(0.426)	(0.440)
Mean Variance-Inflation Factor (VIF)	3.02	3.78	3.02	3.78	3	3.75	3	3.75
$R^{2\ adj}$	0.779	0.764	0.720	0.699	0.780	0.766	0.733	0.713

Notes: N = 92. Robust standard errors in parentheses. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. All continuous variables are log-transformed

Table 7.3 The role of historical entrepreneurial tradition and regional knowledge for start-ups in technology-intensive industries today

	I	II	III	IV	V	VI	VII	VIII
Dependent variable	Self-employment rates 1907				Self-employment rates 1925			
Self-employment rate in science-based industries	0.329***	0.288**	0.357***	0.313**	0.528***	0.536***	0.549***	0.549***
	(0.118)	(0.129)	(0.118)	(0.133)	(0.083)	(0.101)	(0.080)	(0.102)
Self-employment rate in non-science based non-agricultural private sector industries		0.123		0.132		−0.030		−0.000
		(0.193)		(0.201)		(0.194)		(0.196)
Distance to university founded before 1900	−0.015	−0.016			−0.008	−0.008		
	(0.013)	(0.013)			(0.009)	(0.010)		
Distance to technical university founded before 1900	−0.060***	−0.059***			−0.046***	−0.046***		
	(0.019)	(0.019)			(0.014)	(0.015)		
University founded before 1900 (Yes = 1)			0.054	0.057			0.023	0.023
			(0.053)	(0.052)			(0.038)	(0.040)
Technical University founded before 1900 (Yes = 1)			0.247***	0.242***			0.195***	0.195***
			(0.088)	(0.089)			(0.061)	(0.062)
Population density	0.093	0.089	0.102	0.099	0.053	0.051	0.056	0.056
	(0.063)	(0.063)	(0.066)	(0.066)	(0.039)	(0.043)	(0.040)	(0.044)
Distance to nearest coalfield	−0.007	−0.007	−0.011	−0.011	−0.010	−0.010	−0.012	−0.012
	(0.026)	(0.026)	(0.027)	(0.027)	(0.020)	(0.020)	(0.021)	(0.021)
Employment share in manufacturing	0.244	0.191	0.268	0.211	0.031	0.032	0.036	0.036
	(0.215)	(0.244)	(0.220)	(0.248)	(0.080)	(0.081)	(0.081)	(0.081)
Dummies for Federal States	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Constant	−6.211***	−6.252***	−6.432***	−6.475***	−5.130***	−5.132***	−5.280***	−5.280***
	(0.712)	(0.724)	(0.743)	(0.755)	(0.482)	(0.481)	(0.490)	(0.491)
$R^{2\ adj}$	0.660	0.661	0.650	0.652	0.746	0.746	0.742	0.742

Notes: Dependent variable is the average start-up rate in innovative industries in the period 2000–2016. Robust standard errors in parentheses. The number of observations is 92 regions in all models. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. All continuous variables are log-transformed caused by historical levels and may cause multicollinearity problems with the measures of historical entrepreneurship and knowledge.[13] All models indicate that the historical self-employment rate in science-based industries in 1907 and 1925 has a positive effect on entrepreneurship in technology-intensive industries today, while historical self-employment in non-science based industries is insignificant. According to these estimates, a 1% higher historical regional entrepreneurship rate in science-based industries in 1907 is associated with a 0.3% increase in high-tech entrepreneurship in the same region today. The respective effect for the employment share in science-based industries in the year 1925 is 0.5%.[14]

Distance to a technical university founded before 1900 is negatively related to contemporaneous high-tech entrepreneurship, while there is no significant relationship with distance to a classical university. An increase in the distance to technical universities by 1% reduces current technology-intensive entrepreneurship by about 0.04% or 0.05% (Models I, II, V and VI in Table 7.3). The positive role of technical universities is confirmed when introducing binary indicators for university presence instead of the distance measures.

The coefficient estimates in the table suggests that regions hosting a technical university around this time also have an up to 24% higher start-up rate in technology-intensive industries today (Models III, IV, VII and VIII in Table 7.3). There is no significant effect of classical universities or of the control variables.[15]

In order to analyze the interplay of entrepreneurial tradition and the regional knowledge base, we interact our indicators for historical entrepreneurship with the measures for the historical regional knowledge base (Table 7.4). For ease of interpretation, we focus on the binary indicators for the presence of a classical university or a technical university. In the models of Table 7.4 the constitutive term of the self-employment rate represents the effect of historical self-employment in regions that had no classical university or technical university in 1900. In terms of effect size, there is a positive and significant effect of historical science-based entrepreneurship

[13]Again, all estimated coefficients can be interpreted as elasticities that indicate the relative importance of the respective measure since all continuous variables are log-transformed.

[14]As a robustness check, we also interacted the historical self-employment measures with a dummy variable indicating a location in East Germany. There is a significant positive effect for science-based entrepreneurship in the 1925 specifications of the base line models. There is no difference when controlling for the employment share in science-based industries (see Table A4 and A5 in Fritsch and Wyrwich 2018). Since the interaction variables remained insignificant in general, we conclude that the historical self-employment effect is not moderated by the substantial difference in entrepreneurship policies during German separation. Apart from that, a positive interaction for those regions where economic structure and institutions were destroyed to a larger degree indicates that persistent effects of historical self-employment predating these changes are due to cultural not structural components.

[15]In a robustness check we added the two academies of mining (*Bergakademie Clausthal* and *Bergakademie Freiberg*) to the technical universities that existed in the year 1900 (see Table A6 in Fritsch and Wyrwich 2018). Both institutions are borderline cases of a technical university in the year 1900. Considering both institutions as technical universities does not change the results in a meaningful way.

Table 7.4 The interaction between historical entrepreneurial tradition and regional knowledge and its role for start-ups in technology-intensive industries today

	I	II	III	IV	V	VI
Dependent variable	Self-employment rates 1907			Self-employment rates 1925		
Self-employment rate in science-based industries	0.301**	0.307**	0.336**	0.527***	0.545***	0.533***
	(0.137)	(0.128)	(0.133)	(0.109)	(0.105)	(0.113)
Self-employment rate in non-science based non-agricultural private sector industries	0.134	0.057	0.022	0.028	0.024	0.050
	(0.207)	(0.209)	(0.215)	(0.191)	(0.205)	(0.206)
University founded before 1900 (Yes = 1)	0.728	2.045***	0.377	−0.180	−0.647	−0.989
	(1.925)	(0.693)	(1.817)	(0.793)	(0.872)	(0.965)
Technical University founded before 1900 (Yes = 1)	2.151	2.080**	−0.462	3.675**	4.985***	7.513***
	(2.385)	(0.938)	(2.902)	(1.613)	(1.845)	(1.470)
Self-employment rate in science-based industries X University 1900	0.122		−0.364	−0.035		−0.060
	(0.347)		(0.341)	(0.141)		(0.153)
Self-employment rate in science-based industries X Technical university 1900	0.349		−0.636	0.641**		0.570**
	(0.430)		(0.706)	(0.294)		(0.233)
Self-employment rate in non-science based non-agricultural private sector industries X University 1900		0.947***	1.104***		−0.293	−0.293
		(0.325)	(0.326)		(0.387)	(0.406)
Self-employment rate in non-science based non-agricultural private sector industries X Technical university 1900		0.917*	1.384**		2.159**	1.903**
		(0.463)	(0.652)		(0.827)	(0.803)
Population density	0.094	0.093	0.107	0.043	0.061	0.051
	(0.069)	(0.067)	(0.068)	(0.043)	(0.045)	(0.045)
Distance to nearest coalfield	−0.011	−0.016	−0.017	−0.023	−0.014	−0.024
	(0.028)	(0.024)	(0.023)	(0.021)	(0.022)	(0.021)
Employment share in manufacturing	0.211	0.219	0.231	0.052	0.030	0.042
	(0.252)	(0.245)	(0.249)	(0.082)	(0.082)	(0.083)

(continued)

Table 7.4 (continued)

	I	II	III	IV	V	VI
Dependent variable	Self-employment rates 1907			Self-employment rates 1925		
Dummies for Federal States	Yes***	Yes***	Yes***	Yes***	Yes***	Yes***
Constant	−6.517***	−6.576***	−6.522***	−5.202***	−5.272***	−5.167***
	(0.774)	(0.753)	(0.752)	(0.532)	(0.520)	(0.540)
$R^{2\ adj}$	0.654	0.684	0.689	0.752	0.751	0.758

Notes: Dependent variable is the average start-up rate in innovative industries in the period 2000–2016. Robust standard errors in parentheses. The number of observations is 92 regions in all models. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. All continuous variables are log-transformed. Please note that constitutive variables of interactions must not be interpreted as mean effects. The coefficients measure the effect for the case that the other constitutive variable is zero for these regions that resembles the findings of Table 7.3. The interaction of historical self-employment in science-based industries with the classical university and technical university dummy variables yields no significant interaction terms. Thus, when comparing regions that hosted a university in 1900 with regions that did not, there is no difference in the effect of science-based entrepreneurship on current innovative entrepreneurship.

Interacting non-science based entrepreneurship with the dummies for the presence of a classical university or a technical university yields an interesting pattern. The insignificance of the constitutive term of historical non-science based entrepreneurship indicates that this type of self-employment had no long-term effect on technology-intensive entrepreneurship today in those regions that did not host a university in the year 1900. However, the results of the estimates using data for the year 1907 reveal a significantly positive effect for the interaction of historical non-science based self-employment with the presence of a classical university. There is a somewhat weaker relationship for technical universities (Models II and III in Table 7.4).

In the models with data for 1925 we find significantly positive effects of the interaction between the presence of a technical university and the self-employment rate in science-based industries, as well as with non-science based industries. There is, however, no significant relationship for the interaction between both types of self-employment and the presence of a classical university. A 1% increase in non-science based self-employment in 1907 implies a 1% to 1.5% higher start-up rate in high-tech entrepreneurship today (Models II and III in Table 7.4). For 1925, we find an even higher effect of nearly 2.2% (Models V and VI in Table 7.4).[16]

A technical note concerns the technical university and classical university dummy variables. In interaction models these binary variables measure the specific effect of the local presence of classical universities or technical universities for the hypothetical case that the self-employment rate(s) are zero. Therefore, the coefficients of the dummy variables for classical universities and technical universities in Table 7.4 cannot be interpreted as an effect at the mean value (for details see Brambor et al. 2006). Plotting marginal effects of hosting a university at different levels of the self-employment rates reveals that there is a positive stand-alone effect in regions with high levels of historical entrepreneurship.[17]

Altogether, the results suggest that entrepreneurial tradition interacts with knowledge of a more applied character (presence of a technical university), but also with knowledge of a more general character as represented by the presence of a classical university. The insignificance of the interactions between science-based

[16]We ran models with only one interaction term to rule out that the results are driven by using more than one interaction term. This method does not change the results. Splitting the sample of classical universities and technical universities into smaller and larger institutions reveals that the persistent effect of regional knowledge is driven by larger universities (see Table A7 and A8 in the Appendix of Fritsch and Wyrwich 2018).

[17]The plots can be found in the Appendix of Fritsch and Wyrwich (2018). This includes Figure A1 to A16 including a supportive table for reading the plots.

entrepreneurship and the presence of a classical university in 1907 confirms the well-known fact that German classical universities in the early twentieth century had a rather low propensity to cooperate with private firms (Manegold 1989; König 2006). Although the links between technical universities and private sector firms at that time were much more pronounced, these relationships were more commonly developed with well-established larger firms. Given the relatively low propensity of employees of large firms to spin-off (Elfenbein et al. 2010; Parker 2009), knowledge spillovers emerging from cooperation between large firms and universities are less likely to be commercialized via entrepreneurship. The significant interaction between the local presence of a technical university and the level of science-based entrepreneurship in 1925, nearly 20 years later, suggests that this pattern changed during the years between 1907 and 1925.

The considerable correlation between population density and the employment share in manufacturing ($r = 0.7$), may give rise to multicollinearity concerns. However, the mean VIF presented for all models is ca. 3, which suggests that multicollinearity is not a critical concern here.[18] For the year 1925, information about the employment share of science-based industries is also available. This variable is highly correlated with the employment share in manufacturing ($r = 0.68$). Considering this variable instead of the employment share in manufacturing does not change the main results. The coefficient for the share itself is not significantly different from zero. This clearly indicates that it is not the historical presence of science-based industries as such that is important for persistence of entrepreneurship, but the prevalence of self-employment in these industries.[19]

As a further step of analysis we investigate the effect of the universities that were founded before the year 1900 with those that were established at a later point in time. Particularly in the 1960s and 1970s, the German university system was significantly extended by adding several new locations. We introduce dummy variables indicating regions hosting a classical university or technical university founded after 1900. We additionally interact our historical entrepreneurship measures also with the binary markers for universities. The results demonstrate that new universities are not related to high technology entrepreneurship.[20] This pattern suggests that the historical knowledge base is more important for the effect of entrepreneurial tradition on today's technology-intensive entrepreneurship than the newly created universities.

Altogether, the results demonstrate that there is a positive relationship between the historical level of science-based entrepreneurship and current start-up activity in innovative industries. There is also an interesting interaction between the level of

[18]To err on the side of caution, we run all models without the employment share in manufacturing as a robustness check. The results of this exercise reveal no meaningful differences to the set of models presented in Tables 7.3 and 7.4 (see Table A9 and A10 in the Appendix of Fritsch and Wyrwich 2018).

[19]For results, see Table A11, and A12 in the Appendix of Fritsch and Wyrwich (2018).

[20]For results, see Table A14 and A15 in Fritsch and Wyrwich (2018).

non-science based entrepreneurship and the presence of a university. This interaction is particularly pronounced for applied knowledge, as indicated by the presence of a technical university, while the effect of more general knowledge (presence of a classical university) seems to decrease over time.

7.5 Discussion

Analyzing the effect of historical levels of knowledge and entrepreneurship on the formation of innovative new businesses today, we found a number of highly significant relationships that indicate a strong persistence of both regional knowledge and entrepreneurship. One important result is that a history of academic knowledge in natural sciences and engineering, as indicated by the presence of a technical university in the year 1900, has a pronounced effect on the rate of innovative start-ups today, showing remarkable long-term effects of a relatively strong regional knowledge base. We also found a positive effect of recently founded universities on innovative entrepreneurship. This effect is, however, smaller than the effect of institutions that were already in place in the year 1900. This result suggests that the unfolding of the effects of universities on the local economy may require longer periods of time.

A second important result is that our analyses clearly indicate that it is the historical self-employment rate in science-based industries, and not the level of self-employment in non-science based non-agricultural industries, that has a long-lasting effect on innovative entrepreneurship. However, in regions that hosted a classical or a technical university, non-science based self-employment seems to be conducive to technology-intensive start-ups today. Our results suggest that a historically-grown regional knowledge base and a tradition of science-based entrepreneurship, as well as the interaction between the knowledge base and the level of general self-employment are important parts of the landscape for explaining entrepreneurial activities in innovative industries today. These findings are consistent with the knowledge spillover theory of entrepreneurship (Acs et al. 2009, 2013).

Our study has, of course, a number of limitations. First, we have no information about the quality of the universities that existed in the early twentieth century that might provide important insights about their effect on the economy in their region. Moreover, we have no data that would allow us to judge if parts of the effects that we observe are caused by particularly high government transfers at that time. Another limitation is that we do not have any direct measures of a historical entrepreneurship culture, such as the treatment of self-employment in the local media or the entrepreneurship-friendliness of the local government.

A major challenge for further research is to identify the sources of a regional culture of entrepreneurship and how it is transferred over time despite disruptive changes of the framework conditions. It would be interesting to know how regional entrepreneurship cultures have emerged. Hypotheses in this regard stress the role of geographic location, the conditions of the soil and the inheritance law that prevailed in a region (e.g., Freytag and Thurik 2007; Stuetzer et al. 2016). For example, a popular explanation for the pronounced entrepreneurial spirit that is still found in many areas of Baden-Wuerttemberg in southwest Germany argues that the inheritance law in this region created incentives to shift economic activity from agriculture toward some type of craft businesses and this characteristic led to a relatively large number of small businesses (for details, see Fritsch and Wyrwich 2014, 2017a). In contrast, the Ruhr area with its rich coal deposits, was dominated by coal mining for a long time and is characterized by related large-scale industries that prevented the emergence of an entrepreneurship culture (Grabher 1993).[21]

We believe that the basic results of our analysis can be applied to any number of other countries, and that our results convey two important messages for policy makers. First, fostering entrepreneurship in conjunction with a strong regional knowledge base can have long-lasting positive effects on innovative entrepreneurship. Thus, knowledge-intensive regions with a long tradition in entrepreneurship are likely to have better prospects for development. Second, if areas that were particularly entrepreneurial and knowledge-intensive more than 100 years ago do still breed many innovative new businesses, it may be difficult for entrepreneurial laggards to catch up in the short and medium run. However, the effect of historical factors is in no way deterministic. There are regions that were entrepreneurial in the past but lost that characteristic later on, while other regions developed high levels of entrepreneurial activity within relatively short periods of time (for examples, see Sorenson 2017). From a policy perspective, the main questions are: How to foster an entrepreneurship culture? How to improve the regional knowledge base? How to promote the interaction between the knowledge base and entrepreneurship?

A promising starting point for the creation of an entrepreneurship culture is to install an entrepreneurship-friendly institutional framework (see Andersson and Henrekson 2015; Elert et al. 2017; Fritsch and Wyrwich 2017b; Henrekson and Rosenberg 2001). Although there is hardly any way for policy to directly affect informal institutions such as a culture of entrepreneurship (Rodríguez-Pose 2013), it can create formal institutions that steer informal institutions in a certain direction. Well-designed tax policies, for example, could increase the level of entrepreneurship. In this respect, Darnihamedani et al. (2018) show that governments can stimulate innovative entrepreneurship by relieving the tax burden levied against individuals and businesses that reap the rewards of innovation. Measures that could indirectly spur a positive public opinion about entrepreneurship and entrepreneurial behavior are awareness campaigns, e.g., portraying successful entrepreneurs in the media.

Fostering education and other well-designed entrepreneurship-enabling policies may create the knowledge spillovers that are required to achieve economic growth in a knowledge-based entrepreneurial society. For example, as Dilli and Westerhuis (2018) show, closing the gender gap in science education, technology, engineering

[21]This type of explanation seems to hold for similar regions in the UK and US. For details see Chinitz (1961) and Stuetzer et al. (2016).

and mathematics can facilitate innovative entrepreneurial activity. Finally, policy measures that promote networking among actors, particularly between public research institutes and private sector firms, could be helpful for the creation, recognition and realization of entrepreneurial opportunities. In any case, policy makers should be aware that creating an entrepreneurship culture is a long-term task, but that its effect—once established—is long-lasting.

Appendix

Table 7.5 Definition of variables

Variable	Definition
Patents (per 10,000 workforce population)	Number of patents over workforce population aged between 18 and 64 years old
Employment share of R&D employees	Number of employees working as natural scientists or engineer over all employees
Start-up rate technology-intensive industries (per 10,000 workforce population)	Number of start-ups in technology-intensive industries over population in workforce aged between 18 and 64 years old
Classical university founded before 1900 (Yes = 1)	Region hosting a classical university (*Universitaet*) founded prior to the year 1900
Technical university founded before 1900 (Yes = 1)	Region hosting a technical University (*Technische Hochschule*) founded prior to the year 1900
Distance to classical university founded before 1900	Distance in km
Distance to technical university founded before 1900	Distance in km
Self-employment rate in science-based industries 1907	Total number of establishments in science-based industries (“machine, apparatus, and instruments” and “chemical industry”) over all employees
Self-employment rate in non-agricultural non-science based private sector industries 1907	Total number of establishments in non-agricultural private sector industries (excluding science-based industries) over all employees
Self-employment rate in science-based industries 1925	Total number of self-employed persons in knowledge-intensive industries (“machine, apparatus, and vehicle construction”, “electrical engineering, precision mechanics, optics”, “chemicals”, and “rubber- and asbestos”) over all employees

(continued)

Table 7.5 (continued)

Variable	Definition
Self-employment rate in non-agricultural non-science based private sector industries 1925	Total number of self-employed persons in non-agricultural private sector industries (excluding science-based industries) over all employees
Population density 1907/1925	Population 1907/1925 per square km
Distance to nearest coalfield	Distance in km. Information is based on Châtel and Dollfus (1931)
Employment share in manufacturing 1907/25	Number of employees in manufacturing industries over all employees
Employment share in science-based industries 1925	Number of employees in science-based industries divided by all employees

Note: Freelance professions are not considered in the historical self-employment rates because they are included in the "state" sector and cannot be disentangled

Table 7.6 Descriptive statistics

	Mean	Standard deviation	Minimum	Maximum
Patents (per 10,000 workforce population)	3.56	4.11	0.14	29.64
Employment share of R&D employees	0.01	0.01	0.01	0.04
Start-up rate technology-intensive industries (per 10,000 workforce population)	2.518	0.739	0.983	6.011
Classical university founded before 1900 (Yes = 1)	0.18	0.39	0	1
Technical university founded before 1900 (Yes = 1)	0.1	0.3	0	1
Distance to classical university founded before 1900	60.98	39.6	0	163.58
Distance to technical university founded before 1900	95.99	53.47	0	253.01
Self-employment rate in science-based industries 1907	0.41	0.1	0.18	0.83
Self-employment rate in non-agricultural non-science based private sector industries 1907	12.11	2.3	7.88	20.72
Self-employment rate in science-based industries 1925	0.35	0.1	0.15	0.71
Self-employment rate in non-agricultural non-science based private sector industries 1925	10.48	1.28	5.89	13.58
Population density 1907	4.72	0.73	3.52	7.98
Population density 1925	4.84	0.78	3.65	8.4
Distance to nearest coalfield	102.42	89.1	0	357.2
Employment share in manufacturing 1907	35.9	11.48	17.26	69.88
Employment share in manufacturing 1925	26.16	9.61	11.67	54.75

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