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Regional knowledge, entrepreneurial culture, and innovative start-ups over time and space—an empirical investigation

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Abstract We investigate the role of entrepreneurship culture and the historical knowledge base of a region on current levels of new business formation in innovative industries. The analysis is for German regions and covers the time period 1907–2014. We find a pronounced positive relationship between high levels of historical self-employment in science-based industries and new business formation in innovative industries today. This long-term legacy effect of entrepreneurial tradition indicates the prevalence of a regional culture of entrepreneurship. Moreover, local presence and geographic proximity to a technical university founded before the year 1900 is positively related to the level of innovative start-ups more than a century later. The results show that a considerable part of the knowledge that constitutes an important source of entrepreneurial opportunities is deeply rooted in history. We draw conclusions for policy and for further research.

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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 an important role of geographic proximity 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; Boschma 2005; Asheim and Gertler 2006). 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 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

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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.

Empirical research has also clearly shown that the entrepreneurial spirit that is necessary to recognize and realize entrepreneurial opportunities is not evenly spread across space (Sternberg 2009). In particular, it is well documented that such spatial differences in entrepreneurship tend to be highly persistent over longer periods of time (Andersson and Koster 2011; Fritsch and Wyrwich 2014, 2017b; Fotopoulos and Storey 2017; Fritsch et al. 2017). Fritsch and Wyrwich (2014, 2017a) argue that persistence of entrepreneurship over time indicates the role of a region-specific "culture" understood as an informal institution that changes only gradually and over rather long periods of time (North 1994; Williamson 2000). It is, however, largely unclear what the main constituents of such an entrepreneurial culture are, how it emerges, and what other factors might contribute to the explanation of persistence of entrepreneurship.

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?"

Our data cover the development path of regions in Germany from 1907 to 2014, a period of more than 100 years including two lost World Wars and a number of additional disruptions, such as drastic changes of the political regime and massive inflows of refugees after World War II. Given these developments, persistence of entrepreneurship may be regarded as an indication of a regional culture of entrepreneurship. Based on the knowledge spillover theory of entrepreneurship (Acs et al. 2009, 2013), we hypothesize that there is 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. 2, we briefly survey on the literature on the role of regional knowledge and an entrepreneurial tradition of entrepreneurship. Sect. 3 presents our data and the empirical approach. The results are presented in Sect. 4. Section 5 concludes and draws implications for policy and for further research.

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

[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).

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 (Fritsch et al. 2017; Stuetzer et al. 2017). 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]

A regional culture of entrepreneurship can be characterized as an "aggregate psychological trait" (Freytag and Thurik 2007, 123) in the regional population that favors entrepreneurial values, such as individualism, independence, and motivation for achievement. As already mentioned, it can be regarded as a sticky and slowly changing informal institution (North 1994; Williamson 2000). Several studies have indeed shown that regional levels of entrepreneurship tend to be rather persistent over longer periods of time, even surviving massive shocks such as devastating wars or drastic changes of the political regime (Fritsch and Wyrwich 2017b). In Germany, these shocks did not hit all regions in the same way and reshaped the economic and social landscape quite differently (see Fritsch and Wyrwich 2017a). Since these developments rule out that the persistence of entrepreneurship is caused by enduring structural conditions, we argue that a positive relationship between an entrepreneurial tradition (as measured by historical levels of self-employment) and current start-up activity indicates that the presence of a local entrepreneurship culture is the key mechanism behind this persistence.

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 and with information on the presence of universities. In particular, we investigate whether both 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 (Fritsch et al. 2017). 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. Given the severe structural shocks that German regions experienced over the course of the observation period, the key mechanism behind any persistent effect of an entrepreneurial tradition and its interaction with historical knowledge indicates the local presence of an entrepreneurship culture.

3 Data and measurement

Our empirical analysis focuses on German regions and is based on data drawn from current start-up activity and information about historical self-employment rates, industry structure and knowledge sources. The data on new business formation are from the Mannheim Enterprise Panel and allow for identifying innovative start-ups based on their affiliation with certain industries. Like other data sources on start-ups, these data may not have complete coverage of very small start-ups. However, once the firm either is registered, hires employees, asks for a bank loan, or unfolds reasonable economic activities, it is included in the data set and information is gathered on the date when the firm was established.[4]

[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 that 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.

[4] The information in this data base is originally collected by *Creditreform*, Germany's largest credit rating agency, and is prepared by the Center for European Economic Research (ZEW) (Bersch et al. 2014). An alternatively data source to measure entrepreneurship at the regional level is the Establishment History Panel (*BHP*) at the Institute for Employment Research in Nuremberg (*IAB*). A disadvantage of this data is, however, that a new business can be identified only if, and not before, it hires at least one employee subject to Social Insurance. Hence, firms may appear in these statistics only several years after they have been founded.

Information about the historical levels of entrepreneurship is taken from an extensive occupations census from 1925 (Statistik des Deutschen Reichs 1927), and an establishment census from 1907 (Statistik des Deutschen Reichs 1909). For the year 1925, we have detailed information on the "social status" of people that could be either self-employment, paid employment, or non-participation in the workforce. For the year 1907, we have to rely on the number of establishments in private sector industries to construct our historical entrepreneurship measure.

Self-employment in the non-agricultural private sector in 1925 is defined as the number of self-employed in manufacturing and services divided by all employees. For 1907, we use the number of establishments in manufacturing and services (non-agricultural private sector) divided by all employees. We also construct a measure of science-based entrepreneurship. 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. The self-employed in these industries in 1925 constitute 3.23% of all self-employed. For the empirical analysis, the number of self-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%.

By referring to historical self-employment rates as measures of entrepreneurial tradition, our analysis captures the "culture component" of entrepreneurship in an indirect way. Our argument is that if historical self-employment has an effect on current entrepreneurship despite heavy structural shocks, this is due to non-structural factors. Such factors are historically grown positive attitudes towards entrepreneurship, social legitimacy of entrepreneurial behavior, role model effects and local narratives about the positive role of entrepreneurship, all of which indicate an entrepreneurship culture as defined in Sect. 2.

Our indicator for current levels of entrepreneurship is the average start-up rate in technology-intensive industries for the period 2000 to 2014. The start-up rate is the number of newly founded businesses in technology-intensive industries over total employment in the region (including employees in the public sector). We use the common classification of industries according to their innovativeness that is based on their share of R&D inputs (OECD 2005; Gehrke et al. 2010). A problem of this classification is that industry affiliation is a fuzzy criterion because there may be innovative and not so innovative firms in all industries. However, given the limited availability of data on the innovativeness of individual businesses, this is often the only feasible way to identify new businesses as being innovative. The share of new businesses in innovative industries in all non-agricultural start-ups during the years 2000–2014 is 7.9%.

Our main indicators for the 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 (CUs) and technical universities (TUs). We form two binary variables for the presence of a CU or a TU in the region before the year 1900.[5] TUs in Germany began to emerge in the mid-nineteenth century. In contrast to CUs, they had a focus on natural sciences and engineering and were much more oriented towards the commercial application of knowledge (Drucker 1998, 21). While it was rather unusual for German CUs at that time to have cooperative links with private firms, the pronounced collaboration of TUs with the private sector could have made the figure of the entrepreneur more legitimate in regions hosting a TU and may in this way have been conducive to higher levels of self-employment.

All TUs 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 TUs was the German Association of Engineers (Verband Deutscher Ingenieure, VDI).[6] All technical colleges that became TUs before 1900 were located in the capital cities of the Federal States (for details, see Manegold 1989 and König 2006). There is no indication that they were strategically placed primarily in regions with high

[5] There were three CUs 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. Table A.1 in the appendix provides an overview about the universities founded prior to 1900.

[6] 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 TUs was regarded an important means for improving the education of engineers (see König 2006).

levels of self-employment. Today, TUs in Germany represent just one specific type of higher education institution that has relatively strong links to private sector firms.

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.[7] The idea behind these 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 TUs and CUs 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 TUs and CUs, as indicated by the binary variables.

While the spatial definition of administrative districts in the early twentieth century differs from the organization of current planning regions, we are able to assign the historical districts to current planning regions. Planning regions represent functionally integrated spatial units based on travel-to-work patterns and are comparable to labor market areas in the USA.[8] Although all planning regions host at least one university today, the presence of higher education institutions does not play any role in the definition of these regions. If a historical district is located in two or more current planning regions, we assigned the employment based on each region's share of the geographical area. Our regression framework includes the 92 planning regions of Germany.

Figure 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 CUs and TUs. 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 TUs were located in regions with high levels of self-employment in science-based industries. This pattern is more pronounced in 1925.

Figure 2 shows the average start-up rates in technology-intensive industries during 2000–2014. 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 TU in the year 1900 and current rates of innovative new business formation.

Table 1 lists the definition of the variables used in the analysis. Table 2 and Table A.2 in the Appendix present summary statistics and a correlation matrix for these variables.

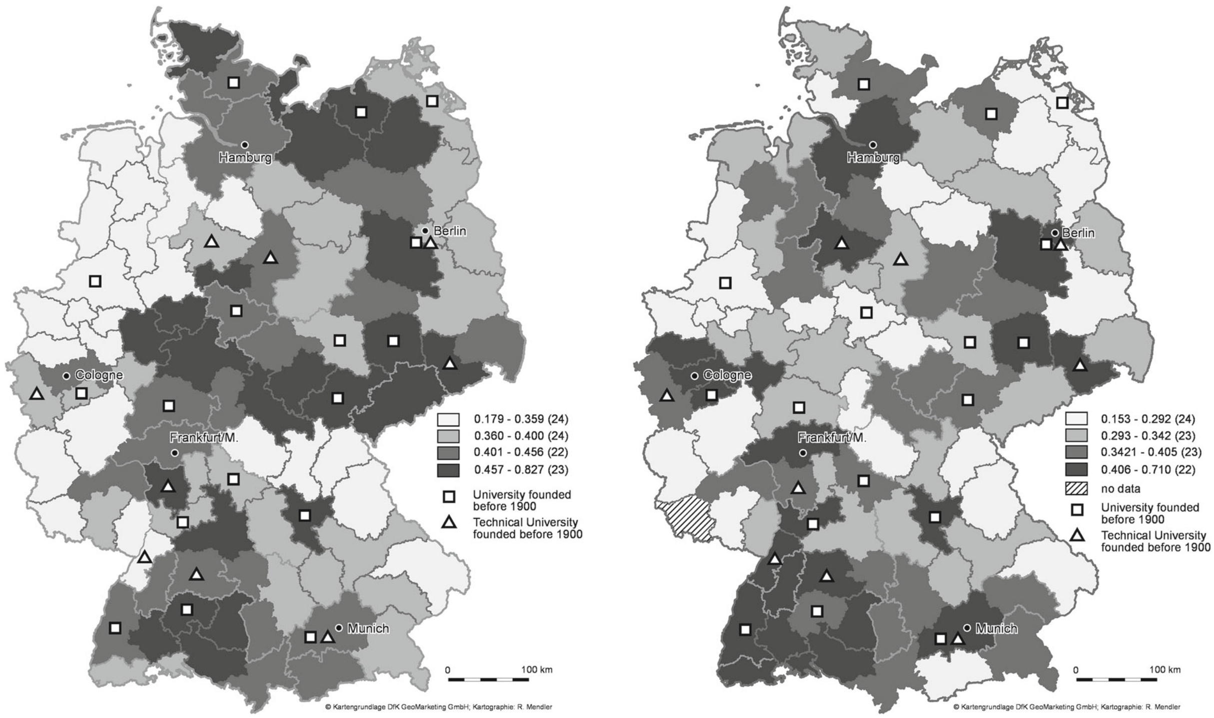
4 Results

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

[7] 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 significant regional variation in literacy levels in Germany between 1907 and 1925, since schooling was compulsory.

[8] The official definition of a planning region as provided by the Federal Institute for Research on Building, Urban Affairs, and Spatial Development (BBSR 2016). There are 96 German planning regions. For administrative reasons, the cities of Hamburg and Bremen are defined as planning regions even though they are not functional economic units. To avoid distortions, we merged these cities with adjacent planning regions. Hamburg is merged with the region of Schleswig-Holstein South and Hamburg-Umland-South. Bremen is merged with Bremen-Umland. Thus, the number of regions in our sample is 92. Furthermore, we exclude the planning region "Saarland" from the regression analysis, since most of the areas within this planning region were not completely under German administration at the time of the 1925 survey.



1907 1925

Fig. 1 Spatial distribution of the self-employment rate in science-based industries of the economy in the years 1907 and 1925

today: the number of patents per person employed,[9] and the employment share of R&D employees.[10] Population density in the year 1907 is included as a "catch-all" variable 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.[11] Since all continuous 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 CU and/or of a TU) are highly significant (Table 3). The coefficients for the presence of a TU are much larger than those for the presence of a CU, suggesting a relatively strong effect of a regional tradition in natural sciences and engineering. The estimated coefficients indicate that regions with a TU have 80% more patents per working population today than regions without any university (model II in Table 3). For CUs, this effect is about 37%. The presence of a TU increases the employment share of R&D employees by 58%, while the presence of a CU increases this share by 25% compared to regions without a CU or TU (model IV in Table 3). The estimates also clearly suggest (models I and II in Table 3) that geographic proximity to CUs and TUs matters. A 1% increase in distance to CUs reduces the patenting rate by 0.1%, while a 1% increase in distance to TUs is associated with a

[9] 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.

[10] 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.

[11] The coalfields considered are those in the Ruhr area, the Saarland, and the Middle German field (Halle-Leipzig). The information is based on the atlas by Châtel and Dollfus (1931).

drop of 0.2%. The effects are slightly smaller for the employment share of R&D employees (0.06% for CUs; 0.13% for TUs).

The results are robust when considering regional control variables for the year 1925 instead of 1907 (Table 3, models V to 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 CUs and TUs in terms of the number of students registered in 1911.[12] We split the data at the median value which implies that CUs with less than 2000 students are marked as small while the respective threshold for TUs is 1000 students. The results indicate that the effects of historical knowledge on today's innovation activities are stronger for larger CUs and TUs (Table A.3 in the Appendix).[13]

4.2 Persistence of entrepreneurship

Table 4 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 caused by historical levels and may cause multicollinearity problems with the measures of historical entrepreneurship and knowledge.[14] 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%.[15]

Distance to a TU founded before 1900 is negatively related to contemporaneous high-tech entrepreneurship, while there is no significant relationship with distance to a CU. An increase in distance to TUs by 1% reduces current technology-intensive entrepreneurship by about 0.04 or 0.05% (models I, II, V, and VI in Table 4). The positive role of TUs 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 TU around this time also have an up to 22% higher start-up rate in technology-intensive industries today (models III, IV, VII, and VIII in Table 4). There is no significant effect of CUs or of the control variables.[16]

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 5). For ease of interpretation, we focus on the binary indicators for the presence of a CU or a TU. In the models of Table 5, the constitutive term of the self-employment rate represents the effect of historical self-employment in regions that had no CU or TU in 1900. In terms of effect size, there is a positive and significant effect of historical science-based entrepreneurship

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

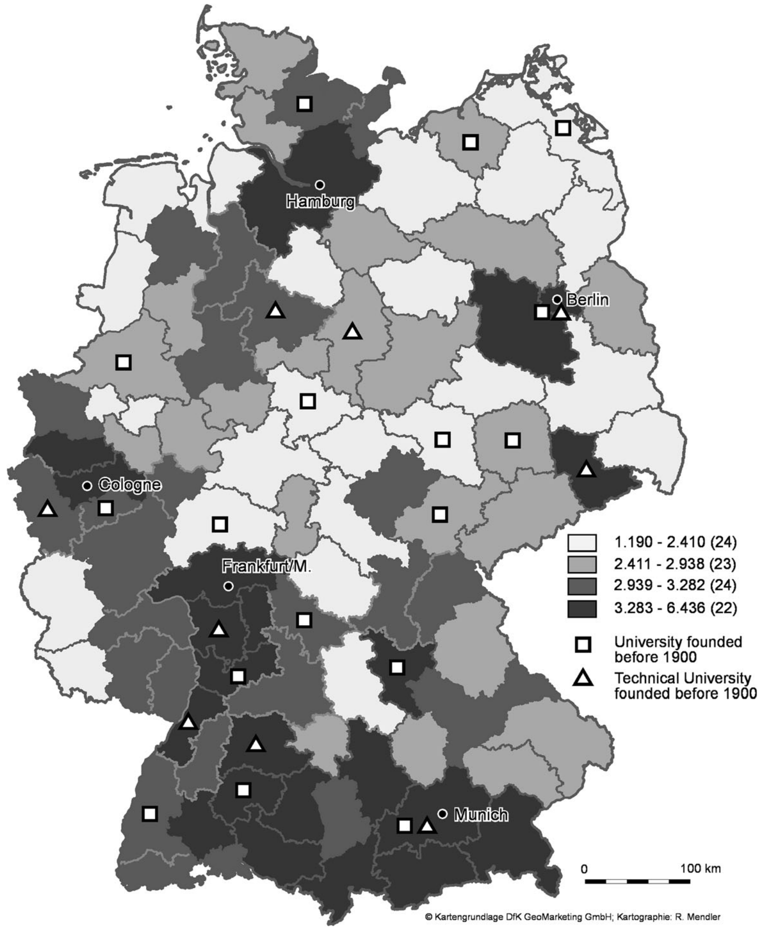
[13] Due to the rather small number of observations, one should not overinterpret the results of the small-large-university distinction. The classification of universities by size is provided in Table A.1.

[14] 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.

[15] 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 (see Table A.4 in the Appendix). There is no difference when controlling for the employment share in science-based industries (see Table A.5 in the Appendix). 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.

[16] 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 (Table A.6 in the Online Resource). Both institutions are borderline cases of a technical university in the year 1900. Considering both institutions as TU does not change the results in a meaningful way.

Fig. 2 Average regional start-up rate in technology-intensive industries 2000–2014



for these regions that resembles the findings of Table 4. The interaction of historical self-employment in science-based industries with the CU and TU 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 CU or a TU 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 CU, as well as a TU (models II and III in Table 5).

In the models with data for 1925, we find significantly positive interaction effects between the presence of a TU 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 CU. 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 5). For 1925, we find

Table 1 Definition of variables

Variable	Definition
Patents (per 10,000 workforce population)	Number of patents over workforce population aged between 18 and 64 years
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
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 kilometers
Distance to technical university founded before 1900	Distance in kilometers
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.
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 km^2
Distance to nearest coalfield	Distance in kilometers. Information is based on Châtel and Dollfus (1931)
Employment share in manufacturing 1907/1925	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

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

Table 2 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)	2.92	0.79	1.19	6.44
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
Employment share in science-based industries 1925	5.42	3.73	0.66	16.85

Table 3 Persistence of regional knowledge

Dependent variables	I Controls 1907	II	III	IV	V Controls 1925	VI	VII	VIII
	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 (yes = 1)	− 0.098***		− 0.063***		− 0.100***		− 0.064***	
	(0.033)		(0.013)		(0.033)		(0.013)	
Distance to technical university founded before 1900 (yes = 1)	− 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***	− 0.0124	0.015		0.257***
		(0.146)		(0.056)	(0.131)	(0.138)		(0.054)
Technical university founded before 1900 (yes = 1)		0.801***		0.578***	0.007	− 0.004		0.591***
		(0.255)		(0.068)	(0.067)	(0.069)		(0.070)
Population density	− 0.062	− 0.0316	0.163***	0.176***	0.690***	0.762***	0.164***	0.175***
	(0.138)	(0.146)	(0.044)	(0.049)	(0.229)	(0.245)	(0.045)	(0.051)
Distance to nearest coalfield	− 0.018	− 0.030	0.042**	0.0351		0.386**	0.055**	0.049**
	(0.068)	(0.070)	(0.020)	(0.024)		(0.149)	(0.022)	(0.025)
Employment share in manufacturing	0.828***	0.909***	0.370**	0.415***		0.822***	0.351***	0.392***
	(0.277)	(0.297)	(0.142)	(0.146)		(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-squared	0.779	0.764	0.720	0.699	0.780	0.766	0.733	0.713

Notes: $N = 92$. Robust standard errors in parentheses. All continuous variables are log-transformed

*Statistically significant at the 10% level; **statistically significant at the 5% level; ***statistically significant at the 1% level

Table 4 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
	Self-employment rates 1907				Self-employment rates 1925			
Self-employment rate in science-based industries	0.297**	0.288**	0.322***	0.310**	0.476***	0.509***	0.494***	0.521***
	(0.116)	(0.121)	(0.115)	(0.123)	(0.077)	(0.090)	(0.075)	(0.091)
Self-employment rate in non-science-based non-agricultural private sector industries		0.0359		0.050		−0.123		−0.010
		(0.208)		(0.208)		(0.174)		(0.174)
Distance to university founded before 1900 (yes = 1)	−0.011	−0.011			−0.004	−0.005		
	(0.012)	(0.011)			(0.009)	(0.009)		
Distance to technical university founded before 1900 (yes = 1)	−0.054***	−0.053***			−0.041***	−0.042***		
	(0.018)	(0.019)			(0.014)	(0.014)		
University founded before 1900 (yes = 1)			0.037	0.038			0.007	0.009
			(0.048)	(0.048)			(0.038)	(0.039)
Technical University founded before 1900 (yes = 1)			0.223***	0.220**			0.175***	0.177***
			(0.083)	(0.084)			(0.059)	(0.060)
Population density	0.078	0.078	0.089*	0.089*	0.0244	0.014	0.027	0.020
	(0.051)	(0.052)	(0.052)	(0.052)	(0.038)	(0.040)	(0.038)	(0.040)
Distance to nearest coalfield	−0.005	−0.005	−0.007	−0.007	−0.007	−0.008	−0.008	−0.009
	(0.025)	(0.025)	(0.025)	(0.025)	(0.019)	(0.020)	(0.020)	(0.020)
Employment share in manufacturing	0.165*	0.153	0.172*	0.155	0.093	0.095	0.097	0.099
	(0.095)	(0.122)	(0.096)	(0.119)	(0.077)	(0.077)	(0.077)	(0.077)
Dummies for Federal States	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.701	0.641	0.333	0.251	1.475***	1.873**	1.248***	1.548**
	(0.438)	(0.608)	(0.405)	(0.586)	(0.355)	(0.717)	(0.326)	(0.677)
Mean VIF	3.19	3.39	3.14	3.33	3.02	3.16	2.98	3.12
R-squared adj.	0.643	0.643	0.634	0.634	0.725	0.726	0.721	0.722

Notes: Dependent variable is the average start-up rate in innovative industries in the period 2000–2014. Robust standard errors in parentheses. The number of observations is 92 regions in all model. All continuous variables are log-transformed

*Statistically significant at the 10% level; **statistically significant at the 5% level; ***statistically significant at the 1% level

Table 5 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
	Self-employment rates 1907			Self-employment rates 1925		
Self-employment rate in science-based industries	0.296**	0.302**	0.327***	0.510***	0.515***	0.517***
	(0.125)	(0.115)	(0.117)	(0.098)	(0.093)	(0.102)
Self-employment rate in non-science-based non-agricultural private sector industries	0.0492	−0.047	−0.082	−0.066	−0.077	−0.063
	(0.213)	(0.206)	(0.209)	(0.173)	(0.180)	(0.185)
University founded before 1900 (yes = 1)	0.160	−2.023**	−2.585***	−0.084	0.524	−0.072
	(0.322)	(0.773)	(0.858)	(0.143)	(0.879)	(1.012)
Technical university founded before 1900 (yes = 1)	0.556	−2.349**	−4.230**	0.666**	−5.042***	−4.571**
	(0.380)	(1.074)	(1.932)	(0.272)	(1.799)	(1.913)
Self-employment rate in science-based industries × university 1900	0.138		−0.288	−0.087		−0.169
	(0.341)		(0.335)	(0.134)		(0.144)
Self-employment rate in science-based industries × technical university 1900	0.388		−0.679	0.589*		0.499**
	(0.389)		(0.632)	(0.301)		(0.225)
Self-employment rate in non-science-based non-agricultural private sector industries × university 1900		0.821**	0.943***		−0.224	−0.046
		(0.312)	(0.299)		(0.374)	(0.400)
Self-employment rate in non-science-based non-agricultural private sector industries × technical university 1900		0.989**	1.488**		2.187***	2.163***
		(0.414)	(0.573)		(0.757)	(0.751)
Population density	0.084	0.080	0.091	0.010	0.023	0.017
	(0.056)	(0.053)	(0.055)	(0.041)	(0.041)	(0.042)
Distance to nearest coalfield	−0.008	−0.012	−0.014	−0.021	−0.011	−0.020
	(0.027)	(0.023)	(0.022)	(0.020)	(0.021)	(0.020)
Employment share in manufacturing	0.158	0.185	0.195*	0.110	0.095	0.103
	(0.120)	(0.115)	(0.116)	(0.078)	(0.078)	(0.078)
Dummies for Federal States	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.258	0.478	0.519	1.536**	1.504**	1.528**
	(0.605)	(0.591)	(0.588)	(0.670)	(0.689)	(0.705)
Mean VIF	3.33	3.33	3.33	3.12	3.12	3.12
R-squared adj.	0.637	0.668	0.673	0.732	0.733	0.742

Notes: Dependent variable is the average start-up rate in innovative industries in the period 2000–2014. Robust standard errors in parentheses. The number of observations is 92 regions in all models. 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

*Statistically significant at the 10% level; **statistically significant at the 5% level; ***statistically significant at the 1% level

an even higher effect of nearly 2.2% (models V and VI in Table 5).[17]

A technical note concerns the TU and CU dummy variables. In interaction models, these binary variables measure the specific effect of the local presence of CUs or TUs for the hypothetical case that the self-employment rate is zero. Therefore, the coefficients of the dummy variables for CUs and TUs in Table 5 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.[18] Splitting the sample of CUs and TUs into smaller and larger institutions reveals that the persistent effect of regional knowledge is driven by larger universities (Table A.8 in the Appendix).

Altogether, the results suggest that entrepreneurial tradition interacts with knowledge of a more applied character (presence of a TU), but also with knowledge of a more general character as represented by the presence of a CU. The insignificance of the interactions between science-based entrepreneurship and the presence of a CU in 1907 confirms the well-known fact that German CUs in the early twentieth century had a rather low propensity to cooperate with private firms (Manegold 1989; König 2006). Although the links between TUs and private sector firms at that time were much more pronounced, these relationships were more with well-established larger firms. Given the relatively low propensity of employees of large firms to spin-off (Parker 2009; Elfenbein et al. 2010), 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 TU 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 (see Table A.2 in the Appendix) may give rise to multicollinearity concerns. However, the mean VIF presented for all models suggests that multicollinearity is not a critical concern here. 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 5 and 6 (Table A.9 and A.10 in the Appendix).

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 (Table A.11, and A.12 in the Appendix). 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 CU or TU founded after 1900 (see Table A.14). We additionally interact our historical entrepreneurship measures also with the binary markers for universities (see Table A.15). While there is no significant effect of newly founded TUs, we find a small positive effect of newly founded CUs. This result 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 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 TU, while

[17] 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 (see Table A.7 in the Appendix).

[18] The plots can be found in the Online Resource (Fig. A.1 to 16 including a supportive table for reading the plots).

[19] Excluding self-employment rates implies that the employment share in science-based industries is weakly significant and positive (Table A.13 in the Appendix).

the effect of more general knowledge (presence of a CU) seems to decrease over time.

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 it may take longer periods of time for the effects of universities on the local economy to unfold.

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, non-science-based self-employment seems to be conducive to technology-intensive start-ups today in regions that hosted a classical or a technical university. 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 for explaining entrepreneurial activities in innovative industries today. These findings are consistent with the knowledge spillover theory of entrepreneurship (Acs et al. 2009, 2013).

Given that Germany experienced a number of disruptive shocks in the last century that reshaped the country's economic structures, the positive effects of high levels of self-employment in the past indicate the presence of a long-lasting entrepreneurship culture. This conclusion is supported by a study of Fritsch et al. (2017) that attempts to identify a regional culture of entrepreneurship understood as an "aggregate psychological trait" (Freytag and Thurik 2007, 123) of the local population. Using data drawn from the personality profiles of the local population, this study finds that regions with high historical self-employment rates tend to have high shares of people with an entrepreneurship-prone personality profile today.

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 towards some type of craft businesses, and this has led to a relatively large number of small businesses (for details, see Fritsch and Wyrwich 2014, 2017b). 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).[20]

We believe that the basic results of our analysis apply to many countries and that they convey two important messages for policymakers. 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

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

entrepreneurship are likely to have better prospects of development. Second, if areas that were most 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, and 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 Henrekson and Rosenberg 2001; Andersson and Henrekson 2015; Elert et al. 2017; Fritsch and Wyrwich 2017b). Although there is hardly any way for policy to directly affect informal institutions such as a culture of entrepreneurship (Rodriguez-Posé 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 the public opinion about entrepreneurship are awareness campaigns (e.g., portraying of successful entrepreneurs in the media) that may trigger a positive perception of entrepreneurial behavior.

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, 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, policymakers should be aware that creating an entrepreneurship culture is a long-term task but that its effect—once established—is long-lasting.

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