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Does Successful Innovation Require Large Urban Areas? Germany as a Counterexample

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Abstract

Popular theories claim that innovation activities should be located in large cities because of more favorable environmental conditions that are absent in smaller cities or remote and rural areas. Germany provides a clear counterexample to such theories. We argue that a main force behind the geography of innovation in Germany is the country's federal tradition that has shaped the settlement structure, the geographic distribution of universities and public research institutions, as well as local access to finance. Additional factors that may play a role in this respect are the system of education and the tax treatment of inheriting a business. We demonstrate the long-lasting effect of the historical political structure and distribution of knowledge sources on innovation activities today. We conclude that historical factors that shape the settlement structure and location of knowledge sources are of key importance for the geographic location of innovation activities.

JEL-classification: 031, R11, L26

Keywords: Innovation, patents, agglomeration economies, cities, Germany

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1. Large agglomerations and innovation[1]

Recent literature has stressed the role of large urban areas for creativity, entrepreneurship, and innovation (Carlino and Kerr 2015; Florida 2002; see Shearmur 2012 for an overview). Based on arguments about the effectiveness of agglomeration economies, many authors claim that large cities are 'innovation machines' and a requirement for any successful innovation activity (Carlino and Kerr 2015; Florida, Adler and Mellander 2017). A recent empirical investigation based on patent data (Fritsch and Wyrwich 2020), however, finds that most countries have a considerable share of successful innovation activities in non-urban areas and, hence, provide striking counterexamples to this popular belief.[2] Moreover, the study confirms that inventors located in urban areas are not more productive in the sense of having more inventions than those in rural regions.

This paper investigates the spatial distribution of innovative activity in Germany, and shows that Germany clearly challenges the 'innovation requires large cities' paradigm. Our aim is to explain why innovation activity in Germany is so geographically decentralized, and how firms located outside of larger agglomerations are able to innovate successfully. We argue that a main explanation for the decentralized geographic structure of innovation activities in Germany is the country's federal tradition, particularly the relatively high level of regional political fragmentation that characterized Germany until the late 19th century. Germany's federal tradition has resulted in a somewhat decentralized settlement structure without dominant metropolitan areas. Instead, there are many small and medium-

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[2] The investigation of Fritsch and Wyrwich (2020) is for 14 developed OECD countries: Canada and the US, a number of European countries well as Japan and South Korea. The analysis shows that South Korea, the US and to a degree Japan are outliers with high share of patents in large metropolitan areas and extremely low shares of patents in non-urban regions. All other countries in the sample show much lower levels of geographical concentration. Fritsch and Wyrwich (2020) conclude from their analysis that results of empirical studies based on US data may not apply to other countries because of the very special spatial structure of innovation activities in the US.

sized cities in relative proximity to one another. The country's federal tradition also contributed to a widespread geographic distribution of universities and other public research institutions, as well as to the presence of locally anchored banks. Other factors that may play a role in the decentralized geographic structure of innovation activity are some peculiarities of the German labor market, the education system, and the tax treatment of inheriting a business.

We argue and provide empirical evidence that the historically grown geographic distribution of knowledge sources in Germany is strongly shaped by the country's federal tradition, and that these realities have long-lasting effects on the regional structure of innovation activities today. Based on our analysis we conclude that the spatial settlement structure, the geographic distribution of knowledge sources, as well as different types of regulation are considerably more important for successful innovation activities than agglomeration economies. Agglomeration economies that influence innovation do of course exist, but they are much less important that some academic literature suggests.

The paper is structured as follows. Section 2 provides an overview of the main arguments that promote the critical importance of large urban areas for successful innovation. Section 3 offers a description of the geographic distribution of innovation activities in Germany. The main explanations for the decentralized geographic structure of innovation activities in Germany are discussed in Section 4. Section 5 then provides empirical evidence on how the historical administrative structures and the geographic distribution of knowledge sources around the year 1900 influence regional innovation activity today. We finally summarize the main results and findings, outline arguments and draw conclusions for theory, and suggest important avenues for further research (Section 6).

2. The geographic distribution of innovation activities—theory and empirical evidence

The belief that large and densely populated urban areas are favorable places for innovation activities (see Audretsch 1988; Feldman and Kogler 2010; Duranton and Puga 2004; Carlino and Kerr 2015), particularly when compared to rural and peripheral regions, is based on presumed locational advantages. The main advantages that are put forward in the literature are: a rich endowment of proximate public and private R&D facilities that encourages knowledge spillovers, abundant input markets that are particularly relevant for R&D, and the inflow of talent and new knowledge from other regions (Florida 2002; Florida, Adler and Mellander 2017). Although these advantages are more or less undisputed,[3] large urban areas may also have disadvantages, such as: high levels of crime, pollution, traffic congestion, and high costs of living, particularly housing costs. Moreover, the relatively easy flow of knowledge within agglomerations may be considered a disadvantage for firms that want to keep their knowledge secret.[4]

There may, however, be any number of factors other than city size and the respective agglomeration advantages that effect the geographic location of innovation activity and its success. The specific economic sector that characterizes a region may have a profound influence on the location and type of innovation activities.[5] Another important factor could be

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[3] Boschma (2005) claims that spatial proximity as such does not automatically lead to spillover and cooperation, but that other types of proximity (e.g., social and cognitive proximity) are required for spillovers to occur. There are a number of examples of larger cities that experienced economic success in the past that did not persist when the given products and technologies matured and new fields of knowledge became relevant. This demonstrates that density does not necessarily lead to persistent successful innovation activities (Storper 2018).

[4] A frequently made argument in favor of large agglomerations is their higher productivity (Ciccone and Hall 1996; Ciccone 2000) that is reflected in higher wages, the ‘urban wage premium’ (Carlino and Kerr 2015, Faberman and Freedman 2016, Glaeser and Maré 2001; Puga 2010; Neffke 2017). This may, however, be of limited relevance because higher productivity is a static phenomenon while innovation is an inherently dynamic process. Hence, for successful innovation it is important that places are able to manage and adapt to change.

[5] The debate as to whether diversity (Jacobs externalities) or specialization of regional activities (Marshall-Arrow-Romer externalities) is more relevant for successful innovation clearly shows that it is not size alone that is relevant. Duranton and Puga (2001) argue in

how the development of a country's spatial system as a whole influences the distribution of cities and population. If we consider even only these two possible factors, it may not be appropriate to look at cities or large urban areas in isolation. Rather, it might be more appropriate to investigate large agglomerations in conjunction with smaller cities and less populated areas, as well as the geographic distances created by extant spatial systems (Crescenzi, Rodriguez-Posé and Storper 2007). It may well be the case that short distances between cities, as are found in Germany, are more conducive to a division of innovative labor between cities, inter-agglomeration spillovers, and a country-wide circulation of knowledge than a spatial structure typical to the US where large metropolitan areas are located far away from one another.

While a significant amount of research focuses on the advantages of large urban areas for innovation, the disadvantages of agglomeration as well as potential advantages of a location in non-urban and peripheral areas have been largely neglected.[6] Hence, there is no clear evidence of how significant the disadvantages of a location in a non-urban area are for innovation activities. Indeed, a highly relevant and intensively discussed question is how to stimulate innovation activities in lagging areas that are often rural and peripheral.[7]

A recent empirical investigation based on patent data for 14 developed OECD countries (Fritsch and Wyrwich 2020) showed that most of the countries in the sample have a considerable share of innovation activities in non-urban areas. This finding provides a striking counterexample to the popular belief of a key role of agglomeration economies for innovation.

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this regard that a diversified creative regional environment is particularly conducive for innovation activity in the early stages of the product life cycle, especially in the development of completely new products, while more specialized locations may be more appropriate at later stages when the product is largely standardized and innovation activities are characterized by a routinized regime (Winter 1984).

[6] Recent work on innovation in peripheral areas are Grillitsch and Nielsson (2015) and Shermur and Doloreux (2016). Eder (2019) provides a survey on studies on innovation in the periphery.

[7] See, for example, the debate about the strategy of smart specialization found in the EU's cohesion policy (e.g., Foray 2014; McCann and Ortega-Argilés 2015).

The analysis shows that South Korea, the US and to a degree Japan are outliers with a high share of patents in large metropolitan areas and extremely low shares of patents in non-urban regions. All of the other countries in the sample show a much less pronounced level of geographical concentration. Moreover, the study shows that inventors located in urban areas are not more productive and do not have more patented inventions than inventors in rural regions. Fritsch and Wyrwich (2020) conclude from their analysis that agglomeration economies do not play a dominant role in the location of innovation activities, but that other factors may be more important, such as the location of knowledge sources. In an earlier paper (Fritsch and Wyrwich 2018) using German data, these authors demonstrated that the regional distribution of historical knowledge sources plays a significant role in the location of current innovation activities. They argue that Germany's federalist tradition influenced the country's political/administrative structures, which in turn shaped the location of historical knowledge sources and the settlement structure. These findings reveal that country-specific characteristics are important factors influencing innovation activity.

3. The spatial structure of innovation activity in Germany

In contrast to countries like the US, France and the United Kingdom, Germany has a rather decentralized settlement structure with many smaller cities in relatively close proximity, and intense shared relationships. As a result, at least one larger city can be reached from anywhere by car or train within one or two hours. This lessens the disadvantages of being located "in the middle of nowhere". Compared to northern regions of Scandinavia or to the US where there are huge distances between the large metropolitan areas, peripheral areas in Germany are much more accessible.

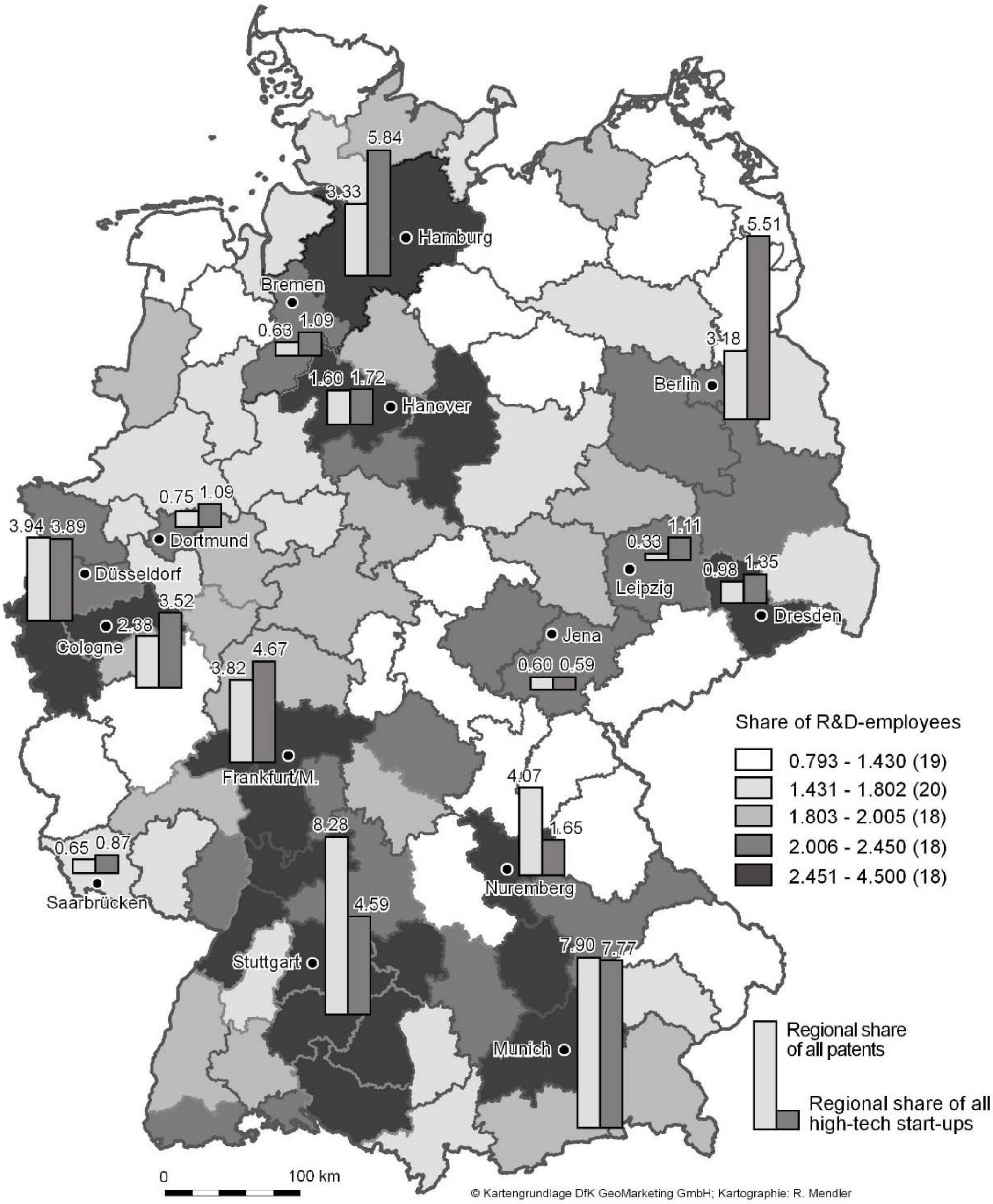

Figure 1: The spatial distribution of R&D employment, patents, and innovative start-ups in Germany, 2010-2015

Figure 1 shows the average shares of R&D employees,[8] the shares of all patent applications and the shares of start-ups in high-tech manufacturing industries[9] in the German planning regions (*Raumordnungsregionen*) that represent functionally integrated spatial units comparable to labor market areas in the United States.[10] Planning regions are larger than what is usually defined as a city or a metropolitan area because they consist of at least one city and its surrounding area. We employ planning regions as spatial units of analysis for three reasons. The first reason is that functional regions are more appropriate because they account for commuter flows and, hence, for the size of the regional labor market that is supposed to be a key advantage of large agglomerations. The second reason is of a statistical nature. It is common practice to regionalize patents by assigning them to the region where the inventor has her or his residence (see Maurat et al. 2008, for details).[11] Since an inventor's residence

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[8] Data on regional private sector R&D employment are from the German Employment Statistics, which covers all employees subject to compulsory social insurance contributions (for details, see Spengler 2008). R&D employees are defined as those with tertiary degrees working as engineers or natural scientists.

[9] The data on new business formation are from the Mannheim Enterprise Panel and allow for the identification of innovative start-ups based on their affiliation with certain industries. 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). Like other data sources on start-ups, these data may not include some of the 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. This information is limited to the set-up of a firm's headquarters and does not include the foundation of branches.

We use the common classification to identify innovative industries that is based on their share of R&D inputs (OECD 2005; Gehrke et al. 2010). The innovative industries comprise high-technology manufacturing industries spending more than 9 percent of their annual turnover on Research and Development (R&D), technologically advanced manufacturing industries with R&D intensities between 3 and 9 percent, and technology-oriented services. A problem with 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.

[10] There are 97 German planning regions. For administrative reasons, the cities of Berlin, Hamburg and Bremen are defined as planning regions even though they are not functional economic units. In our empirical analyses we merged these cities with adjacent planning regions in order to avoid distortions. By doing so, we are left with a total of 93 planning regions in Germany.

[11] If a patent has more than one inventor, the count is divided by the number of inventors and each inventor is assigned his/her share of that patent.

is often located some distance from her/his workplace, restricting the size of the region to the narrowly defined district or city would lead to underestimating the respective city's level of inventive activity. The third reason is that functional regions are more appropriate because they account for spillovers between cities and their surroundings. Consider, for example, when a new business is established in an area adjacent to a city simply because of space availability.

While only four German planning regions (Berlin, Hamburg, Munich, and Cologne) have more than two million inhabitants, a large conglomerate of a number of cities north of Cologne (the Rhine-Ruhr metropolitan region) defines several planning regions with a total of about 10 million inhabitants. Until the 1970s, the northern part of this area was dominated by coal mining and heavy industries and is, despite its large size, characterized by a rather low level of innovation activity.

In accordance with the decentralized settlement structure, innovation activity in Germany is widely spread across the country (Figure 1). The two leading innovative regions (Munich and Stuttgart) have less than 17% percent of the national patent applications and only slightly more than 12% of all start-ups in high-tech manufacturing industries. High levels of innovation activity in terms of shares of R&D employment, patents and innovative start-ups can also be found in many other parts of the country such as the regions of Cologne, Frankfurt, Hamburg, Hanover, Nuremberg (located in former West Germany), and Berlin, Dresden and Jena (located in former East Germany). Many of the regions with low levels of innovation activity do indeed have low population density, but there are many other low-density areas, such as the regions south of Stuttgart, where the level of R&D employment is rather high.

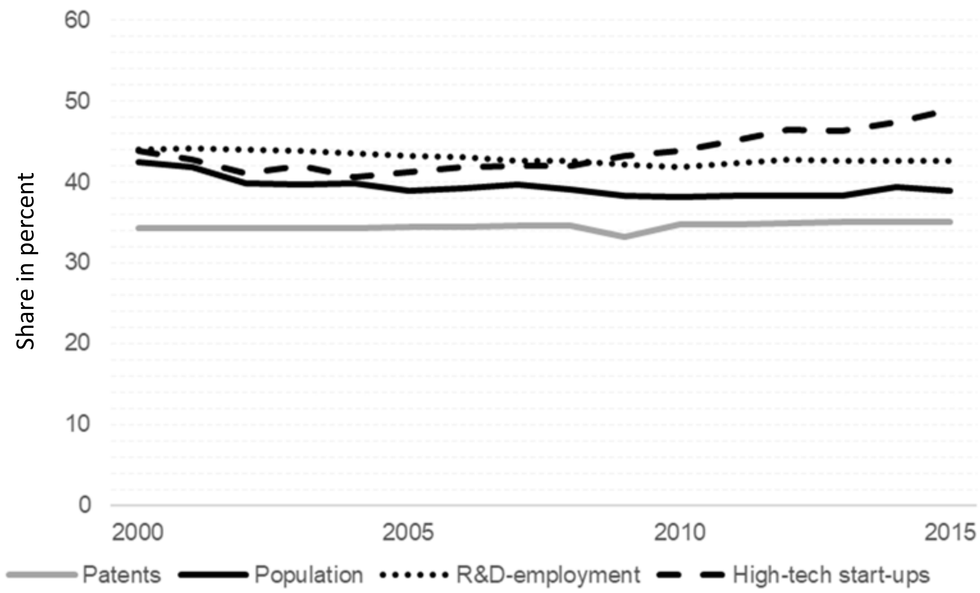

Figure 2: Share of regions with large metropolitan areas (> 1.5 million inhabitants) in innovation activity: Germany 2000 – 2015

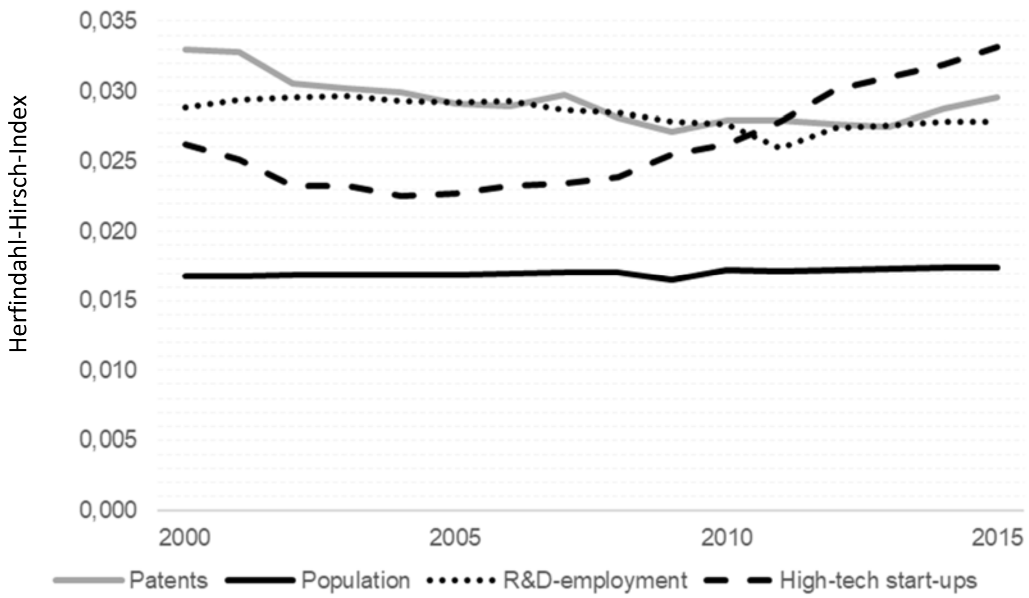

Figure 3: Concentration patterns and trends (Herfindahl index) across planning regions: Germany 2000 – 2015

Figure 2 shows the share of planning regions with more than 1.5 million inhabitants during the years 2000 to 2014, and Figures 3 depicts the general spatial concentration as measured by the Herfindahl index. As can be seen from these figures, the share of regions with large agglomerations and the general level of spatial concentration remained rather constant over time for population, patents, and R&D-employment. However, there is an increasing role of large city regions such as Berlin, Munich and Hamburg for high-tech start-ups that initiated an increase in the geographic concentration for this type of entrepreneurship.

Table 1: Correlation of innovative measures with population density over time (Germany, N=93)

	Population density
R&D employment share (2000-2007)	0.576***
R&D employment share (2008-2014)	0.541***
Patent rate (2000-2007)	0.446***
Patent rate (2008-2015)	0.455***
Hight-tech-start-up rate (2000-2007)	0.519***
Hight-tech-start-up rate (2008-2014)	0.604***

Notes: Coefficients for average values of the respective observation period.

The correlation coefficients between the regional share of R&D employees and population density in the two periods, 2000-2007 and 2008-2014, are slightly decreasing, while we find a small increase of the relationship between population density and the patent rate (Table 1). The values of the correlation coefficients clearly indicate that the role of population density for innovation activities did not become more prominent over the observation period. However, the correlation coefficients for the high-tech start-up rates shows an increasingly positive relationship, indicating the growing importance of agglomeration economies.

A striking counterexample to the 'innovation requires large cities' argument is the location structure of about 1,700 small and medium sized German firms that are world market leaders (so-called 'hidden champions'), i.e., these firms are either among the top three suppliers of their product world-wide, or the leading supplier in the European market (Vonnahme 2019).[12] A little more than 26% of these firms have their headquarters in cities with more than 100,000 inhabitants, while 36% are in smaller towns with between 20,000 and 100,000 inhabitants and 37.5% have their headquarter in locations with less than 20,000 inhabitants (Table 2). About 15.1% of these hidden champion firms are in regions that are classified as peripheral or very peripheral.[13]

Table 2: Headquarters of German hidden champions by community/city and settlement type

	Settlement type 2010				
	Core central	Central	Peripheral	Very peripheral	Total
Large city (> 100 thsd. people)	403	45	0	0	448 (26.5%)
Medium-sized city (20 – 100 thsd.)	280	247	79	2	608 (36.0%)
Larger small town (10 – 20 thsd.)	86	132	79	4	301 (17.8 %)
Smaller town (5 – 10 thsd.)	31	95	84	7	217 (12.8%)
Rural community (< 5 tsd.)	4	31	75	7	117 (6.9%)
Total	804 (47.5%)	550 (32.5%)	338 (20.0%)	20 (1.2%)	1,691 (100%)

Source: Based on Vonnahme and Lang (2018). For definitions of settlement types see Bundesinstituti für Bau-, Stadt- und Raumforschung https://www.bbsr.bund.de/BBSR/DE/Raumbeobachtung/Raumabgrenzungen/deutschland/gemeinden/Raumtypen2010_vbg/raumtypen2010_node.html

The high share of German hidden champions that are located outside of large and densely populated urban areas clearly indicates that agglomeration advantages do not play a dominant role in the success of

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[12] The large majority of these globally successful SMEs are family-owned and belong to the *Mittelstand*. The term ‘Mittelstand’ means more than just being small and medium-sized (SME). According to Pahnke and Welter (2019), another characteristics of Mittelstand firms is that their owner is independent and actively involved in the firm’s strategic development and decision making, and bears the entrepreneurial risks and liabilities. Hence, this definition excludes SMEs that are not owner managed. See also the definition of the German Mittelstand in Audretsch and Lehmann (2016).

[13] At the level of planning regions, 798 (47.2 %) of the hidden champions are located in planning regions that are classified as agglomerations, 262 (15.5 %) are in rural areas and 629 (37.2 %) have a location in moderately congested regions that is the intermediate category.

these firms.[14] A key argument for the relatively favorable conditions for successful innovation activities offered by large urban areas is the existence of larger labor markets that presumably provide more qualified and highly skilled workers (Duranton and Puga 2004; Neffke 2017).[15] The fact that firms located in small villages and rural communities in Germany are able to engage a qualified workforce required for innovative activity and to successfully compete on world markets draws this argument into question.

4. Germany's federal tradition as a main source of the decentralized geographic structure of innovation activity

Our explanation of the rather decentralized spatial structure of innovation activities in Germany is mainly based on the country's high level of historical political fragmentation that arose from a federal tradition and a decentralized spatial settlement structure. A result of the country's federal structure is the wide dispersion of universities and other public research institutes. It is also, at least partly, responsible for the locally embedded decentralized system of financial institutions that makes the availability of finance rather ubiquitous. Additional factors that may also contribute to explaining successful innovation of small firms in remote locations are certain aspects of Germany's labor market regulations, the educational system, and the tax treatment of inheriting a business.

The next section (Section 4.1) focuses on the role of Germany's federal tradition and its consequences for the settlement structure and the

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[14] It should be noted here that the large majority of these firms are located in the area where they were founded several decades ago, and that there is no tendency indicating that these firms will relocate to regions with a higher degree of agglomeration.

[15] There is a wide consensus in the literature that the typical success factors of the German hidden champions are technological leadership in a narrowly defined niche market, high quality of products, and particularly a highly skilled workforce that plays an important role for developing new ideas and engaging in innovation. Many of these firms follow a long-term strategy of implementing progress in rather small steps in order to control risks. Innovation activities tend to be highly customer oriented and are often mostly in a doing, using and interacting mode (Jensen et al. 2007), although many of these firms have co-operative R&D relationship with universities and other research organizations. (see for example, Audretsch and Lehmann 2016; Audretsch, Lehmann and Schenkenhofer 2018; Pahnke and Welter 2018; Rammer and Spielkamp 2019).

geographic distribution of public research. Section 4.2 deals with the decentralized banking system and Section 4.3 briefly explains the potential role of labor market regulations, the educational system, and the tax treatment of inheriting a business for innovation activity in remote locations.

4.1 Germany's federal tradition and its effect on the settlement structure and the geographic distribution of knowledge sources

During the pre-industrial era, many European countries such as France, Spain, England and Habsburg Austria, developed political systems where power and authority was the specific domain of a sovereign ruler. In contrast, the emperor of the Holy Roman Empire of Germany was forced to secure the loyalty of kings, princes, and dukes by granting them concessions with respect to territory and governance, creating an increasingly fragmented political structure. In 1648, when the Treaty of Westphalia finally ended the Thirty Years' War, what we know as Germany today was comprised of hundreds of sovereign statehoods. Although kingdoms such as Bavaria, Prussia and Saxony were able to gain considerable territory, the highly fragmented political environment continued until the establishment of the German Empire in the year 1871 (Kinder 2007).

The fact that today Germany consists of 16 Federal States that have high degrees of political independence is an indication of the long-lasting effects of its historical political fragmentation. Even within the Federal States, there are several layers of well-developed local administrative and political structures (*Regierungsbezirke, Kreise, Gemeinden*) that enjoy considerable self-governance. A consequence of this federal political structure is the decentralized settlement structure found in Germany characterized by some larger cities of about equal importance widely spread across the country. Perhaps more importantly, Germany's capital city of Berlin does not play a dominant role in the exercise of political power or in the concentration of public institutions that characterizes the capital cities of other nations.

Another result of Germany's fragmented political/administrative structure is that the historical competition between the rulers of small states that continues today among the administrative units has led to a rather decentralized distribution of public amenities such as theatres, opera houses, universities, and other public research facilities (Falck, Fritsch and Heblich 2011). For example, the early universities were typically established in a local ruler's capital (for details, see Goethner and Wyrwich 2019), rather than the largest or most economically successful city.[16] Today, there are 94 classical universities and 176 universities of applied science (*Fachhochschulen*)[17] spread across the country, and there is at least one university of applied sciences in each planning region. Nearly all of Germany's universities are public.

Germany is also home to a large number of publicly funded non-university research institutes that are also widely spread across the country. The Max Planck Society (86 institutes with nearly 24 thousand people), the Fraunhofer Society (more than 72 locations with more than 26 thousand employees), the Helmholtz Association (19 research centers with nearly 40 thousand people), and the Gottfried Wilhelm Leibniz Scientific Community (95 institutes with about 20 thousand employees) are among the prominent examples of these institutes that are renowned for the quality and distinction of their work, and represent an important part of their respective region's knowledge base.

4.2 The locally embedded German financial system

The financial system in Germany is characterized by a complex network of financial intermediaries anchored by a three-pillar banking sector. The three pillars include private banks (some of which are large banks that op-

[16] The oldest German university was set-up in the year 1386 in Heidelberg followed by the University of Cologne two years later. The locations of other universities established centuries ago in Germany are Wuerzburg, Leipzig, Rostock, Greifswald Freiburg, Munich Mainz, Tuebingen and Halle. For details see, Goethner and Wyrwich (2019).

[17] The universities of applied sciences are mainly intended to provide undergraduate education with a focus on transferring theoretical concepts and scientific methods into practical application; these universities do not grant PhDs. On average, universities of applied sciences are much smaller than classical universities in terms of the number of personnel and students.

erate internationally), mutual or cooperative credit unions (*Genossenschaftsbanken*), and savings and loan banks (*Sparkassen*) that are publicly held. Employment in savings and loan and cooperative banks is much less geographically concentrated than employment in the large German private banks and their foreign branches (Gaertner and Floegel 2017).

There are relatively few exclusively private banks. Most of these banks are headquartered in large cities, in fact, nearly all of them are located in Frankfurt/Main. The fine-grained network of local savings and loan banks originates in the late 18th century (Allen and Gale 2000; Kindleberger 2015). During the 19th century savings banks spread across the entire country and played a critical role in financing the industrialization process in Germany. Today there are more than 400 savings and loan banks in Germany with the primary purpose of providing financial services that benefit the public interest. Their shareholders are usually one or several single local public units (e.g., local districts; *Kreise)*, and the business of a savings and loan bank (mainly the provision of financial services) are more or less focused on the economy within the geographic units their local shareholder(s) represent. Each savings and loan bank comes under the jurisdiction of a Federal State Bank (*Landesbank*) that covers one or more Federal States and fulfills the role of being the regional clearing house for liquidity (for details see Hackethal 2004; Floegel and Gaertner 2018).

The more than 900 cooperative banks in Germany tend to be much smaller than the savings and loan banks and are widely spread across the country, most of these banks also have a regional focus.[18] They are supposed to provide financial services for their members, many of them smaller local businesses. Based on their ownership structure and their history, one can distinguish between several types of cooperative banks. Another distinguishing feature is the specific national umbrella organization to

[18] The first credit unions originated in the mid-19th century resulting from a variety of initiatives. The focus of these cooperatives was on traders, shop owners and artisans, as well as establishment in rural areas to serve the needs of agrarian communities.

which the cooperative bank is attached. These umbrella organizations provide a set of services that include publicly representing the interests of their members. Credit cooperatives and savings banks in Germany play an important role in providing financial services to local businesses,[19] including the world market leaders of the German *Mittelstand* that are located in rural and remote areas.

Typically, local businesses have a long standing and trusting relationship with their banks that is used as collateral and security for credit. Guinanne (2001) and Floegel (2018) explain the success of the credit cooperatives and savings banks by referring to their ability to make use of superior information and their capacity to impose cheap but effective sanctions on potential defaulters. The ability to make credit decisions for businesses that are nearby enables profitable lending to informationally opaque SMEs that often appear rather risky. Hence, based on hard information alone, these firms would be typically rejected credits by non-local banks (Floegel and Gaertner 2018). Credit cooperatives and savings banks are also better able to develop loan terms more closely in accordance with the needs of the borrowers than the large national banks.

The market for venture capital (VC) in Germany emerged considerably later than in the US and the United Kingdom but has been functioning quite well for several decades. Fritsch and Schilder (2008, 2012) found that, in contrast to what is reported for a number of other countries including the US, a regional equity gap for VC does not exist in Germany. A possible explanation for this is the country's decentralized spatial structure (see also Scheuplein and Kahl 2017).[20] Given the decentralized spatial structure of Germany's banking system, as well as the organizational

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[19] The savings banks and cooperative banks provide about two-thirds of all financing of *Mittelstand* companies, and about 43 percent of the loans to other companies and households (Audretsch and Lehmann 2016).

[20] The average volume of VC investment in Germany is, however, considerably smaller than in the US. Given the openness of the German economy and the presence of international VC suppliers, this is obviously not an issue of a 'too small' amount of available funds, but may be primarily caused by a lack of promising innovative start-ups that want to grow rapidly (see Roland Berger et al. 2018).

structure of the banking sector, one may conclude that these factors contribute to the emergence and viability of SMEs outside of large cities, including the *Mittelstand*.

4.3 Labor market regulation, the education system and the taxation of inheriting a business

German labor market regulation and the apprenticeship system are additional factors that might contribute to explaining how German firms in rural and remote areas manage to be economically successful. In Germany, workers with a secondary education (*Facharbeiter*) that acquire their basic occupation-specific training in the apprenticeship system, are available even in the thin labor markets that characterize smaller cities and rural areas. In fact, by far the largest group of these workers (*Facharbeiter*) is not trained in large firms but in smaller ones. Hence, the workforce required by German SMEs are frequently educated and trained on site. A characteristic of German universities is that there are no huge qualitative differences up to the Master level, and that a standard level of tertiary education in the most popular disciplines is provided even in rather peripheral areas.

An important characteristic of labor market regulation in Germany is the high level of protecting employees from dismissal (Audretsch and Lehmann 2016; Herrmann 2018). This is one of the reasons why workers in Germany do not often change employers. In fact, it is not unusual, particularly in rural areas and smaller cities, that people work for the same employer their entire career. As a result, workers tend to show high levels of identification with “their” firm and are willing to acquire firm-specific skills that can be rather important for the quality of the products and the overall competitiveness of the firm.

Many of the *Mittelstand* firms that constitute a large part of the German world market leaders are rather old, and have been owned by the same family for generations. This intra-family transfer of firm ownership was facilitated by rather favorable inheritance taxes (for details, see Berghoff and Köhler 2019). This favorable tax treatment of the inheritance of firms is based on the belief that a business belongs not only to an individual but also to the family.

5. The impact of federal tradition, historical knowledge sources and population density on today's regional innovation activity

We will now attempt to empirically test our argument that the distribution of innovation activity in Germany is strongly shaped by the country's federal tradition. We will also test the hypothesis that the level of regional innovation activity tends to be rather persistent over longer periods of time. The next section (Section 5.1) discusses ways of identifying the effect of Germany's federal tradition on the regional persistence of innovation activities. Section 5.2 introduces the empirical approach and the definition of variables, while Section 5.3 presents and discusses the results.

5.1 Identifying the role of Germany's federal tradition

We contend that specific aspects of Germany's historical development are keys to understanding why innovation-promoting factors are not just concentrated in a few large cities, but are rather equally spread across regions. But, because there is a plethora of factors and very little regional variations with respect to these factors, a multivariate analysis becomes rather meaningless. For example, there are no regions without local savings banks. Savings banks are more or less equally well represented in large cities as well as non-urban areas. Hence, the prevalence or paucity of savings banks cannot be used to explain regional differences in innovation activity.[21] The same applies to labor market regulation, the educational system, and inheritance taxes, all of which are fundamentally uniform across regions.

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[21] Our argument regarding the long-term effects of a federal tradition is not about the number of savings banks and universities per region. Therefore, an assessment of regional differences in the number of savings banks is not of interest in the described context.

Institutions of higher education and research are spread quite evenly across the regions of Germany. One issue with measuring the impact of a federal tradition based on the presence of universities is that many universities were founded in recent decades after the territorial integration of the country, and not as a result of historical territorial fragmentation.[22] One way to circumvent this concern, is to assess the role of universities that were founded prior to the territorial integration of Germany. As previously mentioned, early universities were typically set-up in the capitals of the local rulers (for details, see Goethner and Wyrwich 2019), so that their location was not primarily determined by city size, economic success or federal spatial planning.

Regions with a long tradition of hosting or being in close proximity to universities may, however, have a persistent advantage with respect to innovation activity. Fritsch and Wyrwich (2018) argue that a more significant and more important part of the available knowledge for innovation activity is of tacit character, i.e., it is attached to people and, therefore, regionally bounded. Due to the stickiness of tacit knowledge, it tends to remain with the local population and is passed down through generations. This characteristic, as well as the continuity of well-established institutions of higher education and research (such as universities), affects the persistence and the scope of regional knowledge levels and profiles over longer periods of time. Since a significant part of the regional knowledge base is geographically bounded, its (persistent) effect on innovation activity should decrease as the distance to early universities increases.

To underline the importance of historical structures, we analyze the effect of the distribution of knowledge sources at the outset of the 20th century on regional innovation activities today. Moreover, we show the persistent effect of entrepreneurship in terms of self-employment in innovative industries on the formation of innovative businesses today. Moreover, we

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[22] Many universities that were founded in the 20th century were established with a main motivation of promoting regional development in lagging regions (for details, see Goethner and Wyrwich 2019).

control for other influences of Germany's federal tradition beyond hosting historical centers of knowledge production by considering dummies for the historical states the regions belonged to before the foundation of the German Reich in 1871.

5.2 Empirical approach and variable definition

We apply planning regions (*Raumordnungsregionen*) as the spatial framework for our analysis (see Section 3.). Our dependent variables are three measures of current regional innovation activity with their average values during the years 2000-2014:

- Our first variable is the number of patents per 10,000 workforce population (individuals between the ages of 18 and 64). Patents are taken from the OECD regional patent database (RegPat) and are assigned to the region in which the inventor claims his or her residence (see Section 3.). 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 the patent.
- Our second variable is the share of R&D employees in total regional employment (see Section 3.).
- Our third variable is the number of new businesses in innovative manufacturing industries (see Section 3.) per 10,000 workforce population in the region.

Because knowledge spillovers are highly localized and sticky (Anselin et al. 1997; Fritsch and Aamoucke 2013), we use a distance measure that is the minimum distance between a region and a university that existed prior to 1900. We assume that the spillovers from universities will decay with increasing geographic distance. An additional advantage of the distance measure is that it rules out that the spillover effect is driven by the low number of regions that hosted a university at that time. We chose the year 1900 for measuring this type of historical knowledge base because it marks the end of a first wave of technical universities that were established in Germany, a process that began in the late 19th century.[23]

The early technical universities in Germany were quite different from the classical universities. A main distinguishing characteristic of technical universities at that time was their focus on natural sciences and engineering. This focus dictated the type of research conduct by technical universities. Most of this research had a strong orientation towards the commercial application of knowledge (Drucker 1998, 21). Classical universities, on the other hand, focused on the arts and humanities. While it was rather unusual for classical universities in Germany to have cooperative links with private firms, technical universities showed pronounced levels of collaboration with the private sector.[24] It is important to distinguish between classical universities and technical universities because the knowledge base originating from technical universities may be particularly relevant for innovation activities.

All of the nine technical universities that existed in the year 1900 developed from technical colleges (*Polytechnische Hochschulen*) that were founded in the 19th century as a reaction to the rapidly growing demand for more focused scientific research and education (Drucker 1998; Carlsson et al. 2009).[25] The locations of all of the nine technical colleges that became technical universities before 1900 were mainly determined by political/administrative factors since they were all in the capital cities of German States (for details see König 2006, and Manegold 1989). Mainly

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[23] Nearly all of the other technical universities that exist today were founded many decades later.

[24] These differences between classical and technical universities were rather specific for that time. Today, the profiles of technical universities in Germany does not differ much from other universities. There could have been differences in the quality of universities in the early 20th century which we cannot measure. Please note that there is no pronounced regional variation in literacy levels in Germany in the early 20th century since schooling was compulsory.

[25] The main political force behind the upgrading of technical colleges to technical universities was the German Association of Engineers (*Verband Deutscher Ingenieure*, VDI). An important 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).

to rule out a spurious correlation between the effect of historical universities, but also of local employment structures, we also control for the historical employment share in science-based industries. This data is taken from an occupation census that was gathered in the year 1925 (Statistik des Deutschen Reichs 1927).

An important variable used to define agglomeration economies is population density. Population density is also thought to influence a variety of other factors such as wages and land prices, which are closely correlated. According to the standard theories concerning the spatial distribution of innovation activity (Section 2), population density positively stimulates innovation activity. In our empirical analysis we rely primarily on the historical population density found around the year 1900.[26] Using both historical population density and distance to universities at the beginning of the 20th century may allow us to test which factor is more important in explaining innovation activity and entrepreneurship today. An important advantage of including historical population density instead of population density today is that this variable is not influenced by current levels of innovation activities.

We also control for the employment share of manufacturing industries and the minimum distance to the nearest coal mines. The employment share of manufacturing and the minimum distance to the nearest coal mine account for the sectoral structure of the regional economy. The rationale for including the distance to the nearest coal mine is that regions located close to a coal mine tend to have high shares of large scale industries and, therefore, to be characterized by low levels of self-employment (Glaeser, Kerr and Kerr 2015; Stuetzer et al. 2016; Fritsch, Obschonka and Wyrwich 2019). We use the values of these variables taken from the establishment census conducted in 1907 (Statistik des Deutschen Reichs 1909).

[26] This information is taken from census data as of 1907 (Statistik des Deutschen Reichs 1909).

German Federal States play an important role in developing regional policies. We use dummy variables to account for the role of political/administrative factors in current innovation activity and historical political differences. As already mentioned, we also include dummies for the historical States to which the regions belonged before the foundation of the German Reich in 1871. By doing so, we can control for additional influences of Germany's federal tradition other than the influences of historical centers of knowledge production.

Table 3: Definition of variables

Variable	*Definition*
Patents 2000-2014 (per 10,000 workforce population)	Number of patent applications in the 2000-2014 period over workforce population between the ages of 18 and 64.
Employment share of R&D employees	Number of employees working as natural scientists or engineer over all employees.
Start-up rate in technology-intensive manufacturing industries (per 10,000 workforce population)	Number of start-ups in technology-intensive manufacturing industries over workforce population between the ages of 18 and 64.
Distance to the nearest classical university founded before 1900	Distance in km to the nearest classical university founded prior to the year 1900.
Technical university founded before 1900 (Yes=1)	Distance in km to the nearest technical university founded prior to the year 1900.
Employment share in science-based industries 1925	Number of employees in science-based manufacturing ("machine, apparatus, and vehicle construction"; "electrical engineering, precision mechanics, optics"; "chemicals"; "rubber and asbestos") over all employees
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.
Population density 1907	Population in the year 1907 per square km.
Distance to nearest coalfield	Distance in km., information is based on Châtel and Dollfus (1931).
Employment share in manufacturing 1907	Number of employees in manufacturing industries over 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.

In models for current levels of innovative start-ups we control for the historical level of self-employment in the year 1907 measured as the number of non-agricultural establishments over all employees. We distinguish between self-employment in science-based industries and non-science-based industries.

As discussed in Section 5.1, we do not include indicators for the presence of financial institutions in this analysis because of the more or less equal distribution of local cooperative and savings banks. We also abstain from measures for the presence of VC companies because the location of these type of financiers is highly demand driven, i.e., they are in regions that have relatively numerous innovative start-ups. Moreover, Fritsch and Schilder (2008, 2012) have shown that VC investment in Germany does not require geographic proximity between the VC company and the portfolio firm.

Table 3 gives an overview of the definition of variables used in our empirical analysis. Table A2 in the Appendix provides descriptive statistics for these variables and Table A3 show their correlations.

5.3 Results

The results of our main analysis are presented in Table 4. We split the sample into two periods (2000-2007 and 2008-2014) to investigate whether the influence of historical characteristics varies over time. A first important result is that the historical population density in 1907 is not related to current innovation activity and entrepreneurship (Models I - III). There is only a significant relationship between current population density and start-up activity (Table A4). In contrast to historical population density, the distance to pre-1900 universities plays an important role. In line with our hypothesis, distance to a classical university or to a technical university that existed prior to 1900 is negatively related to the regional shares of R&D employees and to patenting activity more than 100 years later (Models I - III). As expected, the considerably higher coefficients for the distance to the nearest technical university clearly indicate that being close to a technical university is much more important in determining innovation input and output today than being located near to a classical university.

Table 4: The relationship between the distance to historical centers of knowledge production and innovation and entrepreneurship to-day

	I	II	III	IV	V	VI
	2000-2007					
	Innovative start-ups	R&D employment	Patents	Innova-tive start-ups	R&D employment	Patents
Population density 1907	0.023	0.017	-0.244*	0.094	0.167*	-0.013
	(0.082)	(0.068)	(0.124)	(0.072)	(0.089)	(0.146)
Distance to a classical university founded before 1900	-0.014	-0.054***	-0.056**			
	(0.013)	(0.014)	(0.027)			
Distance to a technical university founded before 1900	-0.053**	-0.113***	-0.133***			
	(0.021)	(0.018)	(0.037)			
Employment share in science-based industries 1925	0.047	0.160***	0.281***			
	(0.077)	(0.060)	(0.073)			
Self-employment rate in science-based industries 1907	0.273			0.351**		
	(0.189)			(0.162)		
Self-employment rate in non-science based non-agricultural industries 1907	-0.044			-0.011		
	(0.214)			(0.227)		
Distance to nearest coalfield	-0.023	0.039	-0.025	-0.020	0.055	-0.000
	(0.024)	(0.026)	(0.075)	(0.026)	(0.034)	(0.083)
Employment share in manufacturing 1907	0.336	0.363	0.354	0.444*	0.850**	1.004**
	(0.288)	(0.280)	(0.395)	(0.247)	(0.364)	(0.464)
R-squared	0.676	0.769	0.878	0.624	0.601	0.814
	2008-2014					
Population density 1907	0.021	-0.007	-0.193*	0.086	0.146	0.011
	(0.086)	(0.072)	(0.114)	(0.081)	(0.091)	(0.126)
Distance to a classical university founded before 1900	-0.012	-0.039***	-0.0531**			
	(0.016)	(0.014)	(0.0239)			
Distance to a technical university founded before 1900	-0.078***	-0.109***	-0.0858***			
	(0.025)	(0.020)	(0.0315)			
Employment share in science-based industries 1925	0.024	0.170**	0.272***			
	(0.078)	(0.067)	(0.0727)			
Self-employment rate in science-based industries 1907	0.261			0.314*		
	(0.198)			(0.180)		
Self-employment rate in non-science based non-agricultural industries 1907	0.099			0.166		
	(0.237)			(0.254)		
Distance to nearest coalfield	-0.042	0.030	-0.0140	-0.040	0.046	0.009
	(0.028)	(0.021)	(0.0690)	(0.029)	(0.028)	(0.075)
Employment share in manufacturing 1907	0.255	0.147	0.201	0.350	0.589	0.781*
	(0.292)	(0.336)	(0.377)	(0.277)	(0.388)	(0.438)
R-squared	0.713	0.713	0.876	0.638	0.541	0.825

Notes: Ordinary least squares regressions. Robust standard errors in parentheses. The number of observations (regions) is 92. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. All continuous variables are log-transformed. All models include dummy controls for the historical and the current states regions are located in. Historical data for the Saarland are not available to the authors.

The distance to a historical technical university is also negatively related to the emergence of innovative start-ups today, while there is no such influence for distance to a classical university. This may indicate the importance of a regional tradition of research in engineering and natural sciences for innovative new businesses. The employment share in science-based industries in the early 20th century is also positively and significantly related to the employment share of R&D employees and patenting activity, while there is no such relationship with innovative start-up activity. It is remarkable that the coefficients for the knowledge indicators are relatively stable over the two investigated time periods.

Since it may be argued that the insignificance of historical population density is due to a high correlation with the knowledge indicators, we also run the analyses without the distance to historical universities and the employment share in science-based industries (Models IV - VI). We find that the relationship between population density and current levels of innovative activity remains statistically insignificant except for the level of R&D employment in the period 2000-2007, where the coefficient of historical population density is statistically significant at the 10% level. Based on these results we can conclude that innovation in Germany does not require large cities. Any potential effects of cities on innovation activity are absorbed by distance to historical centers of knowledge production. There is also no statistically significant influence of the historical controls for access to natural resources and industry structure.

The models without knowledge indicators also yield a highly significant effect of the self-employment rate in science-based industries in the year 1907, while the historical self-employment rate in non-science-based industries remains insignificant. These results indicate the importance of a regional tradition of innovative entrepreneurship, while a general tradition of self-employment in the region appears to be unimportant for innovative start-ups. This pattern was obviously absorbed by including the employment share in science-based industries in Models I - III.[27]

In further robustness checks, we restricted the analysis to West German regions to rule out that our findings are driven by post-socialist East Germany and peculiar effects of economic transition (Table A5 in the Appendix). We also run the main models without dummies for historical and current federal states in order to rule out that the main findings are driven by model over-specification (Table A6 in the Appendix). These robustness checks clearly confirm the findings of our main analysis.

Table 5: The relationship between the distance to historical centers of knowledge and the regional share of R&D employment 1976-2016

	I	II	III	IV
	1976-1983	1984-1994	1995-2005	2006-2016
Distance to a classical university founded before 1900	-0.070***	-0.066***	-0.055***	-0.031*
	(0.020)	(0.019)	(0.017)	(0.016)
Distance to a technical university founded before 1900	-0.105***	-0.115***	-0.125***	-0.125***
	(0.021)	(0.019)	(0.018)	(0.019)
Population density 1976/1984/1995/2006	0.457***	0.348***	0.213***	0.140*
	(0.096)	(0.086)	(0.072)	(0.077)
Distance to nearest coalfield	0.114***	0.079***	0.047**	0.022
	(0.030)	(0.025)	(0.022)	(0.025)
Employment share in manufacturing 1907	0.070	0.209	0.392	0.316
	(0.337)	(0.318)	(0.283)	(0.321)
Dummies for Federal States	Yes***	Yes***	Yes***	Yes***
Constant	-6.923***	-5.706***	-4.418***	-4.004***
	(0.906)	(0.849)	(0.735)	(0.806)
R-squared adj.	0.709	0.717	0.715	0.651

Notes: N=70. 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. Historical data for the Saarland are not available to the authors.

[27] Recent research indicates that there is also an interaction effect on current innovation activity between historical entrepreneurship culture and historical centers of knowledge production (Fritsch and Wyrwich 2018).

In order to determine if the effect of historical knowledge sources and agglomeration economics on current innovation activities is decreasing or increasing over time, we consider four sub-periods from 1976 to 2016. Due to data constraints, this analysis must be restricted to the regional share of R&D employment. We also have to exclude East Germany in this analysis because reliable data on R&D employment in this part of the country is only available from the mid-1990s onward. We find that the coefficient estimates for distance to historical centers of knowledge production, particularly for technical universities, are relatively stable over time (Table 4) while the coefficients for the influence of population density show a significant decrease over the last four decades. This clearly indicates that the explanatory power of population density is not increasing over time, but that the role of agglomeration economies for R&D activities has decreased in recent decades.

6. Conclusions

6.1 Findings

Some standard theories suggest that successful innovation activity highly benefits from agglomeration economies and may require a location in a large city. The fact that most developed countries do not show a strong geographic concentration of innovation activities in large cities (Fritsch and Wyrwich 2020) suggests that factors other than agglomeration economies are more important. In order to identify such factors, we investigate the geographic distribution of innovation activities in Germany. A distinguishing feature revealed in the case of Germany is that there are numerous small and medium-sized firms located 'in the middle of nowhere' that operate very successful on global markets (Section 3).

In Section 4, we identify and discuss four main factors that determine the geographic distribution of innovation activity in Germany and facilitate successful innovation activity in rural and remote areas. The first, and probably most important factor, is Germany's pronounced federal tradition arising from a historical epoch when the territory was split into hundreds of kingdoms and dukedoms that enjoyed a high degree of political autonomy. This political and administrative fragmentation not only led to a rather decentralized settlement structure with no dominant capital city, but in the German context created a spatial configuration where even peripheral areas are well with the reach of larger cities and important knowledge sources. It also resulted in our second factor: a rather even distribution and decentralized infrastructure of universities and non-university public research institutions that generate knowledge and provide education.

A third factor is the abundance of locally embedded financial institutions. The number of savings and loan banks (*Sparkassen*) and the mutual or cooperative credit unions (*Kreditgenossenschaften*), even in rural and remote areas, is conducive to financing economic activities. The local embeddedness of these financiers helps overcome information asymmetries that impact credit decisions. This decentralized financial system with many locally embedded actors is also clearly rooted in Germany's pronounced federal tradition. There are several aspects to the fourth factor all dealing with the establishment of businesses and employment patterns. German labor regulations create an environment that incentivizes laborers to acquire firm-specific skills and develop loyalties to a single employer. The type of education provided by technical universities and Germany's apprenticeship system facilitates the availability of a highly qualified workforce even in small towns and medium sized cities. The relatively generous inheritance tax laws are conducive to the establishment of family firms and generational ownership patterns that are key characteristics of German *Mittelstand* firms.

In Section 5, we discuss our empirical analysis where we investigate the factors that determine the level of innovation activity in a region. Our analysis focuses on historical knowledge and the degree of agglomeration as measured by population density. This analysis shows strongly significant effects of historical knowledge sources such as the presence of universities in the year 1900, and the employment shares in science-based industries more than 100 years ago. There is also a positive relationship between the level of innovation activity and population density. Our results also reveal that the importance of agglomeration economies for innovation activities is decreasing in recent decades, while the effect of historically grown factors remains largely unchanged.

Our results clearly suggest that population density and agglomeration economies do not play a dominant role for regional innovation activity in the Germany context. We conclude that standard theories suggesting large cities induce more productivity and higher levels of innovation activities ignore other more important influences such as: the role of history, the educational system and the spatial structure of the financial system. Hence, policy decisions based on the theory of 'innovation requires large cities" may be rather misguided and counterproductive. Furthermore, results from other analyses clearly suggest that Germany is not a unique case when it comes to the role of non-metropolitan areas for innovation activity (Fritsch and Wyrwich 2020).

6.2 Contribution to theory development

We agree that a good theory is a radical simplification of reality by focusing on the most relevant factors and relationships. Our finding that agglomeration economies do not play a dominant role for the location of successful innovation activities in Germany, nor in many other countries, clearly suggests that the standard theory is missing other more relevant variables.

One category of variables that might be included in a more relevant approach to explain successful regional innovation could be measures that represent the comprehensive settlement structure of a country, as well as the specific size of single agglomerations. Such measures may build on travel times between larger cities and the distance to knowledge sources. Such measures may also reflect inter-agglomeration knowledge spillovers and the integration of a region into the interregional division of innovative labor (Crescenzi, Rodriguez-Posé and Storper 2007).

We also make the case that the level of innovation activity in a region may be rather persistent over longer periods of time. This explains why Germany's history of political fragmentation and the resulting federal tradition has left a remarkable imprint on innovation activity today. Hence, history and the resulting political/administrative structures have pronounced effects on settlement structures, as well as the regional distribution of public institutions such as universities and research institutes. In Germany, the geographic location of local banks is also strongly influenced by these political/administrative factors. Moreover, certain types of regulations, such as employee protection against dismissals, the education system and inheritance tax laws can have important effects. All these factors are candidates for being included in the development of more sound theories that are urgently needed to inform innovation policy.

6.3 Policy implications

A main policy implication of our research is that innovation does not require large cities but can also be successful in remote and rural regions. Hence, concentrating public spending on R&D in large agglomerations that already have well-developed sources of funding for innovation is not necessarily the best strategy to be recommended. Accordingly, there is every reason to believe that arguments in favor of policy programs such as the EU Smart Specialization Strategy (Foray 2014; McCann and Ortega Argilés 2015) that aim at stimulating regional development of low-density lagging regions by initiating and supporting innovation processes are based on sound reasoning and research.

Our analysis also shows the importance of regulatory frameworks, the existing spatial structures, and a region's history, and that any regionally targeted innovation-related policy should take these factors into account. Regions with long histories of innovation activities may require somewhat different innovation policy measures than regions where innovation activities start more or less from scratch.

6.4 Avenues for further research

Our analyses suggest several avenues for future research. One type of research that we believe to be promising is to conduct country-specific case studies that might provide other examples of environments where innovative activity is not just concentrated in large cities and that might uncover other factors that influence the geography of innovation. Our case study of Germany highlights influences such as the role of political/administrative structures, the settlement structure, the geographic distribution to knowledge sources, the banking system, and a number of formal institutions like labor regulations. This evidence suggests a more detailed investigation into the role of these factors in the location of innovation activity may further our understanding of this phenomenon.

A second and complementary strand of analysis is to investigate why firms in remote rural areas continue to be innovative and economically successful. How do these firms acquire the qualified labor that they need for their innovation activities? What are the framework conditions that enable or impede successful innovation in rural and remote areas? How important is a decentralized settlement structure with a diversity of easily accessible smaller and medium-sized cities for innovation in rural areas?

A third challenge is to explain why innovation behavior in a region is persistent over time. What are the relevant mechanisms that lead to persistence? Does public expenditure on research play a role in this persistence? To what extent can policy stimulate innovation activities in less innovative areas? What is a reasonable length of time before significant changes of regional innovation activities can be expected?

All these analyses should also distinguish between different types of innovation, such as radical vs. incremental, high-tech vs. low-tech, science-based vs. engineering or artistic-based. Such types of empirical analyses should provide a more relevant basis for policy decisions than the ‘innovation requires large cities’ paradigm.

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Appendix

Table A1: List of universities founded prior to the year 1900

Type of higher education institution	Planning region	Size (number of students 1911)
Classical universities		
Universitaet Berlin	1101	Large (7585)
Universitaet Muenchen	910	Large (6942)
Universitaet Leipzig	1404	Large (4088)
Universitaet Bonn	505	Large (3805)
Universitaet Freiburg	811	Large (3080)
Universitaet Goettingen	305	Large (2476)
Universitaet Heidelberg	812	Large (2452)
Universitaet Marburg	601	Large (2240)
Universitaet Halle	1503	Large (2209)
Universitaet Kiel	101	Large (2063)
Universitaet Tuebingen	806	Small (1979)
Universitaet Muenster	511	Small (1969)
Universitaet Jena	1603	Small (1902)
Universitaet Wuerzburg	918	Small (1449)
Universitaet Gießen	601	Small (1315)
Universitaet Greifswald	1303	Small (1165)
Universitaet Erlangen	906	Small (1104)
Universitaet Rostock	1302	Small (920)
Technical Universities		
Technische Hochschule Muenchen	910	Large (2376)
Technische Hochschule Berlin	1101	Large (1959)
Technische Hochschule Darmstadt	605	Large (1231)
Technische Hochschule Karlsruhe	805	Large (1052)
Technische Hochschule Dresden	1401	Large (1022)
Technische Hochschule Hannover	307	Small (836)
Technische Hochschule Stuttgart	810	Small (580)
Technische Hochschule Aachen	501	Small (557)
Technische Hochschule Braunschweig	301	Small (370)

Notes: The planning region 601 hosts two classical universities (Marburg; Gießen). Based on the sum of students the planning region is counted as hosting a large classical university. *Source: Deutsche Hochschulstatistik (1929).*

Table A2: Summary statistics

	Mean	Standard Deviation	Minimum	Maximum
Average high-tech start-up rate 2000-2007	2.91	0.81	1.16	6.52
Average R&D -employment share 2000-2007	1.81	0.77	0.68	4.45
Average patent rate 2000-2007	4.65	3.4	0.37	14.45
Average high-tech start-up rate 2008-2014	2.27	0.72	0.91	5.5
Average R&D employment share 2008-2014	1.98	0.78	0.75	4.51
Average patent rate 2008-2014	5.01	3.4	0.36	14.98
Population density 1907	4.73	0.73	3.52	7.98
Distance to a classical university founded before 1900	61.98	39.6	0	164.58
Distance to a technical university founded before 1900	96.99	53.47	0	254.01
Employment share in science-based industries 1925	5.41	3.74	0.66	16.84
Distance to nearest coalfield	101.32	89.25	0	357.2
Employment share in manufacturing 1907	26.31	5.11	15.13	34.85
Self-employment rate in science-based industries 1907	0.41	0.1	0.18	0.83
Self-employment rate in non-science-based/non-agri-cultural industries 1907	12.1	2.3	7.88	20.72

Table A3: Correlation matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Average high-tech start-up rate 2000-2007													
2	Average R&D employment share 2000-2007	0.671												
		[0.000]												
3	Average patent rate 2000-2007	0.702	0.637											
		[0.000]	[0.000]											
4	Average high-tech start-up rate 2008-2014	0.908	0.583	0.686										
		[0.000]	[0.000]	[0.000]										
5	Average R&D employment share 2008-2014	0.644	0.964	0.652	0.566									
		[0.000]	[0.000]	[0.000]	[0.000]									
6	Average patent rate 2008-2014	0.684	0.612	0.977	0.677	0.636								
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]								
7	Population density 1907	0.319	0.448	0.177	0.354	0.385	0.167							
		[0.002]	[0.000]	[0.090]	[0.000]	[0.000]	[0.110]							
8	Distance to a classical university founded before 1900	-0.145	-0.307	-0.109	-0.142	-0.227	-0.106	-0.246						
		[0.169]	[0.003]	[0.299]	[0.178]	[0.030]	[0.313]	[0.018]						
9	Distance to a technical university founded before 1900	-0.432	-0.599	-0.363	-0.448	-0.599	-0.313	-0.374	0.013					
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.002]	[0.000]	[0.902]					
10	Employment share in science-based industries 1925	0.354	0.582	0.148	0.273	0.538	0.131	0.609	-0.206	-0.38				
		[0.001]	[0.000]	[0.161]	[0.009]	[0.000]	[0.212]	[0.000]	[0.048]	[0.000]				
11	Distance to nearest coalfield	0.102	-0.031	0.077	0.098	-0.02	0.138	-0.416	-0.057	0.064	-0.174			
		[0.328]	[0.765]	[0.464]	[0.352]	[0.846]	[0.188]	[0.000]	[0.587]	[0.547]	[0.096]			
12	Employment share in manufacturing 1907	0.198	0.437	-0.063	0.15	0.345	-0.081	0.683	-0.235	-0.266	0.686	-0.409		
		[0.059]	[0.000]	[0.548]	[0.155]	[0.001]	[0.441]	[0.000]	[0.024]	[0.010]	[0.000]	[0.000]		
13	Self-employment rate in science-based industries 1907	0.158	0.137	0.022	0.093	0.139	0.045	-0.169	-0.102	-0.087	0.276	0.376	0.097	
		[0.130]	[0.190]	[0.833]	[0.373]	[0.183]	[0.672]	[0.105]	[0.332]	[0.408]	[0.008]	[0.000]	[0.358]	
14	Self-employment rate in non-science-based non-agricultural industries 1907	0.233	0.238	-0.111	0.219	0.171	-0.087	0.382	-0.136	-0.244	0.488	0.067	0.564	0.495
		[0.025]	[0.022]	[0.290]	[0.035]	[0.101]	[0.406]	[0.000]	[0.197]	[0.019]	[0.000]	[0.523]	[0.000]	[0.000]

Notes: ****: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level.

Table A4: The distance to historical centers of knowledge production and innovation and innovative entrepreneurship today: control for current population density

	I	II	III	IV	V	VI
	2000-2007			2008-2014		
	Innovative start-ups	R&D employment	Patents	Innovative start-ups	R&D employment	Patents
Population density 2000/2008	0.203**	0.129*	-0.116	0.267***	0.132	-0.018
	(0.100)	(0.077)	(0.133)	(0.096)	(0.091)	(0.125)
Distance to a classical university founded before 1900	-0.009	-0.051***	-0.059**	-0.005	-0.036***	-0.054**
	(0.013)	(0.013)	(0.026)	(0.016)	(0.013)	(0.023)
Distance to a technical university founded before 1900	-0.043**	-0.106***	-0.135***	-0.062***	-0.100***	-0.083**
	(0.020)	(0.021)	(0.039)	(0.022)	(0.024)	(0.032)
Employment share in science-based industries 1925	-0.013	0.130**	0.249***	-0.060	0.131**	0.227***
	(0.074)	(0.057)	(0.083)	(0.069)	(0.063)	(0.081)
Self-employment rate in science-based industries 1907	0.401**			0.434**		
	(0.173)			(0.174)		
Self-employment rate in non-science-based/non-agricultural industries 1907	-0.034			0.109		
	(0.208)			(0.226)		
Distance to nearest coalfield	-0.012	0.050**	-0.011	-0.026	0.044**	0.004
	(0.024)	(0.025)	(0.077)	(0.028)	(0.021)	(0.069)
Employment share in manufacturing 1907	0.150	0.235	0.146	0.016	-0.010	-0.051
	(0.257)	(0.273)	(0.417)	(0.234)	(0.331)	(0.387)
R2	0.706	0.776	0.872	0.756	0.722	0.871

Notes: Ordinary least squares regressions. Robust standard errors in parentheses. The number of observations (regions) is 92. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. All continuous variables are log-transformed. All models include dummy controls for the historical and the current states regions are located in. Historical data for the Saarland are not available to the authors.

Table A5: The distance to historical centers of knowledge production and innovation and innovative entrepreneurship today: West Germany

	I	II	III	IV	V	VI
	2000-2007			2008-2014		
	Innovative start-ups	R&D employment	Patents	Innovative start-ups	R&D employment	Patents
Population density 1907	0.027	-0.004	-0.266**	0.030	-0.036	-0.221*
	(0.086)	(0.068)	(0.129)	(0.083)	(0.070)	(0.115)
Distance to a classical university founded before 1900	-0.004	-0.049***	-0.054**	0.006	-0.028*	-0.044*
	(0.015)	(0.017)	(0.026)	(0.018)	(0.016)	(0.023)
Distance to a technical university founded before 1900	-0.053**	-0.115***	-0.111***	-0.077**	-0.109***	-0.072***
	(0.024)	(0.020)	(0.028)	(0.029)	(0.022)	(0.027)
Employment share in science-based industries 1925	0.010	0.155**	0.246***	-0.017	0.169**	0.241***
	(0.074)	(0.062)	(0.068)	(0.070)	(0.070)	(0.070)
Self-employment rate in science-based industries 1907	0.269			0.295		
	(0.190)			(0.182)		
Self-employment rate in non-science-based/non-agricultural industries 1907	0.002			0.180		
	(0.210)			(0.225)		
Distance to nearest coalfield	-0.012	0.037	-0.027	-0.040	0.024	-0.015
	(0.027)	(0.029)	(0.085)	(0.031)	(0.023)	(0.076)
Employment share in manufacturing 1907	0.356	0.387	0.472	0.266	0.191	0.294
	(0.268)	(0.277)	(0.387)	(0.268)	(0.332)	(0.366)
R2	0.611	0.746	0.807	0.611	0.688	0.787

Notes: Ordinary least squares regressions. Robust standard errors in parentheses. The number of observations (regions) is 70. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. All continuous variables are log-transformed. All models include dummy controls for the historical and the current states regions are located in. Historical data for the Saarland are not available to the authors.

Table A6: The distance to historical centers of knowledge production and innovation and innovative entrepreneurship today: no controls for historical and current states

	I	II	III	IV	V	VI
	2000-2007			2008-2014		
	Innovative start-ups	R&D employment	Patents	Innovative start-ups	R&D employment	Patents
Population density 1907	0.103*	0.018	0.291	0.175***	0.007	0.325
	(0.060)	(0.090)	(0.229)	(0.064)	(0.086)	(0.214)
Distance to a classical university founded before 1900	-0.009	-0.050***	-0.057	-0.011	-0.034***	-0.0430
	(0.016)	(0.014)	(0.050)	(0.019)	(0.013)	(0.0456)
Distance to a technical university founded before 1900	-0.060***	-0.126***	-0.195***	-0.073***	-0.123***	-0.145***
	(0.019)	(0.020)	(0.048)	(0.022)	(0.020)	(0.0414)
Employment share in science-based industries 1925	0.058	0.168***	0.171	0.008	0.179***	0.144
	(0.065)	(0.048)	(0.164)	(0.071)	(0.048)	(0.156)
Self-employment rate in science-based industries 1907	0.088			0.065		
	(0.161)			(0.182)		
Self-employment rate in non-science-based/non-agricultural industries 1907	-0.025			0.056		
	(0.192)			(0.225)		
Distance to nearest coalfield	0.026	0.013	0.017	0.029	0.006	0.0482
	(0.017)	(0.018)	(0.054)	(0.020)	(0.018)	(0.0520)
Employment share in manufacturing 1907	-0.157	0.088	-1.766***	-0.296	-0.117	-1.592***
	(0.263)	(0.254)	(0.602)	(0.267)	(0.282)	(0.548)
R2	0.287	0.557	0.230	0.312	0.498	0.215

Notes: Ordinary least squares regressions. Robust standard errors in parentheses. The number of observations (regions) is 92. ***: statistically significant at the 1% level; **: statistically significant at the 5% level; *: statistically significant at the 10% level. All continuous variables are log-transformed. Historical data for the Saarland are not available to the authors.