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The Role of Congestion-impacted Accessibilities for Innovation and Entrepreneurship

Linda Aranka Maria Bandelow

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Vorsitz:	Prof. Dr. Maximilian Schiffer
Prüfer*innen der Dissertation:	1. Prof. Dr. Hanna Hottenrott
	2. Prof. Dr. Rolf Moeckel

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Abstract

Innovation is a key driver of regional competitiveness and growth, and location factors can enhance firms' innovation performance. Startups, in particular, contribute to technological progress through their innovative products and services. While the relationship between local characteristics and innovation activities has been extensively researched, the extent to which improved transport-based accessibility facilitates innovation and entrepreneurship remains largely unknown. This thesis utilizes data from a Germany-wide agent-based transport model to derive travel times and accessibilities for different modes of transport while accounting for road congestion. The first study investigates the impact of accessibility on local innovation activities using both patent application data and a novel innovation indicator based on website texts. The results suggest that regions with better accessibility have higher levels of inventive and innovative activities, with different modes of transport acting as substitutes in this relationship. The subsequent chapter focuses on startups and the challenges they face due to the liability of newness. This study combines the role of accessibilities on new firm founding rates in Germany with qualitative interview data from eleven German startups on their business location assessment methods. The quantitative results indicate that regions with better accessibility have higher levels of startup founding activity. This insight is supported by qualitative data, which suggests that accessibility is essential for founders due to the availability of qualified workers and the minimization of transportation costs in more accessible regions. These findings have implications for research on transport accessibility, startup location choices, and the strategies employed by founders compared to established firms. The final chapter investigates the influence of a startup's location on the effectiveness of public support through subsidies. Public policies aim to provide support, such as startup subsidies, to overcome early-stage financing constraints that may hinder investment and firm development. Results based on detailed information on founder and startup characteristics show that better accessibility, particularly better accessibility to a highly-skilled workforce, increases the effectiveness of subsidies. Specifically, subsidies trigger more additional own-financed R&D when startups have better access to potential R&D employees. However, local accessibility does not appear to affect non-R&D-related outcomes. Overall, these three studies build on existing literature and provide insights into the role of transport accessibility in local innovation and entrepreneurship activity. The findings can benefit policymakers, innovators, entrepreneurs, and subsidy providers.

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1 | Introduction

1.1 Motivation

Developing new ideas, creating products, and innovating has long been known to be a key driver for societal and economic growth (Malecki and Malecki, 1991; Rodríguez-Pose and Crescenzi, 2008). Furthermore, the persistent implementation of novel ideas over multiple generations has significantly enhanced the quality of life (Grossman and Helpman, 1994). This dynamic has prompted numerous researchers to investigate how innovation is brought out best, how it can be supported and enhanced, and in which places people are most innovative. Many studies show that some regions experience greater economic growth than others, suggesting that location factors may influence a region's ability to innovate and develop economically. Early studies on this relationship were conducted in the last century, for example, by Romer (1990), Helpman (1992), Aghion and Howitt (1992), and Acemoglu (1997). Firms that are focusing on developing new products hope to see an increase in their firm growth and profits, which early and recent research results confirm: Innovative activities of firms have been found to increase business performance, the creation of jobs, and regional growth (Grossman and Helpman, 1994; Frenkel and Shefer, 1996; Harhoff, 1999; Feldman, 2004). In established firms, innovation activities are often carried out in efforts to enhance their market competitiveness; however, radical innovation is found to be disproportionately driven by startup companies (Acs and Audretsch, 1988; Schneider and Veugelers, 2010). Yet, emerging enterprises encounter various obstacles in introducing their offerings to the market and achieving sustainable growth. Strategic business planning, human resources, product innovation, and workplace environment require meticulous attention, and financial backing from outside sources, for example, public subsidies, is often necessary.

Geographic location can significantly influence these factors, as funding opportunities and access to skilled labor or resource materials may vary regionally. Additionally, location factors can affect local innovation and entrepreneurship due to variations in the opportunity to cooperate with other firms or research facilities and knowledge spillovers (Audretsch and Feldman, 2004; Unger et al., 2011). Over the past decade, entrepreneurship research has focused on understanding this dynamic. Hence, in addition to firm size, workforce size, and other organizational attributes, a firm's location and regional characteristics are continually investigated for their potential impact on economic and innovation outcomes.

Regional economic development is primarily facilitated by access to knowledge, people, goods, and services. This dynamic is dependent on the connectedness of people through in-person or online communication but also on the mobility and transport accessibility of people, materials, and products (Rode et al., 2017). Individuals such as workers, employers, customers, and service providers play a crucial role in this scenario as they need to travel from A to B, commute to work, reach recreational facilities, or purchase new products and task services. As such, mobility, accessibility, and interconnectedness are key factors in our daily lives, even as digitization rapidly advances. Accordingly, the relationship between mobility and innovation is quite complex, as both can influence one another. Mobility and connectivity, for example, can be improved by technological innovation and vice versa. Thus, some studies have investigated the relationship between mobility, accessibility, and regional economic development (Feldman and Audretsch, 1999; Berliant et al., 2006). In these studies, researchers have often focused on comparing cities' and rural areas' mobility offerings and their impact on economic development. However, research examining the impact of transport accessibility on economic and innovative behavior at a fine-grained level beyond the urban/rural dichotomy is still limited. Some influential areas that do not fit in one category or the other might have been overlooked in this regard and do not get the attention of researchers and policymakers that they require:

> *"Policymakers in non-metropolitan regions are frequently confronted with a brain drain and a potential lack of human capital."* (Haisch et al., 2017)

Building on these considerations, in this thesis, I examine the extent to which innovation and entrepreneurship are influenced by location factors, with a particular focus on transport accessibility. I employ a novel agent-based modeling approach necessary to calculate a transport accessibility measurement on a fine-grained zonal level. With this measure, it can be distinguished between different modes of transport (car, train, bus, and others), and potential traffic congestion is also included. I use this measurement to examine its effects on local innovation behavior, being the overarching topic of Chapter 2; on the founding and location choices of startup companies discussed in Chapter 3; and on the effectiveness of startup subsidies in Chapter 4. Each subsequent chapter examines the respective research dynamics with transport accessibility as the common denominator. This allows an in-depth analysis of which variables are affected by accessibility, if any, and to what extent. My research indicates that innovation – as measured by patenting activity and a score for firms' innovative activity derived from website texts – and entrepreneurship are positively related to better transport accessibility. This correlation extends to startup founding rates in regions with better accessibility. Qualitative data from interviews with startup founders further reveal that location is crucial for new company creators. While accessibility is not directly identified as a critical factor, variables dependent on transport accessibility, such as human capital availability and commutes, are highly valued. Moreover, the detailed analysis in Chapter 4 indicates that startup subsidies are more effective in better accessible locations, increasing investments and employee numbers in R&D.

Overall, this thesis aims to identify factors influencing innovation and entrepreneurial activities and determine how they can be effectively supported. My findings contribute to understanding how regional characteristics impact innovation ecosystems and how firms can optimize their performance while re-contributing to their location. Therefore, these dynamics can improve regional economic performance through employment growth and increased living standards (Grossman and Helpman, 1994). The insights of the studies inform about firms' (re-)location options, policymakers' decisions regarding startup subsidies placement, and the strategic development of transport systems. The results are additionally relevant to transport infrastructure planners as mobility and accessibility continue to increase in importance and complexity with a growing global population.

1.2 Context and Related Literature

In the following section, I will review essential literature on the subject to provide a foundation for the analysis presented in my three essays.

Prior research has examined the factors contributing to why some regions perform and develop better economically and inventively than others. Researchers found that especially the factors: access to highly-skilled (knowledge) workers, agglomeration benefits, or the availability of financing and subsidy programs have a regional impact (Feldman, 1994; Black and Henderson, 1999; Glaeser and Gottlieb, 2009; Carlino and Kerr, 2015). Information spillovers and the presence of large knowledge producers, such as universities, have been additionally identified as key drivers of increased innovation in certain regions (Czarnitzki and Hottenrott, 2009). Furthermore, knowledge transfer can be facilitated through research institutions, qualified and specialized human capital, local customers, suppliers, competitors, and collaboration partners (Hottenrott and Lopes-Bento, 2015; Fudickar and Hottenrott, 2019). Therefore, specific local milieus may facilitate knowledge exchange and spillovers, which are crucial for a firm's innovation performance (Buenstorf et al., 2015; Fudickar and Hottenrott, 2019).

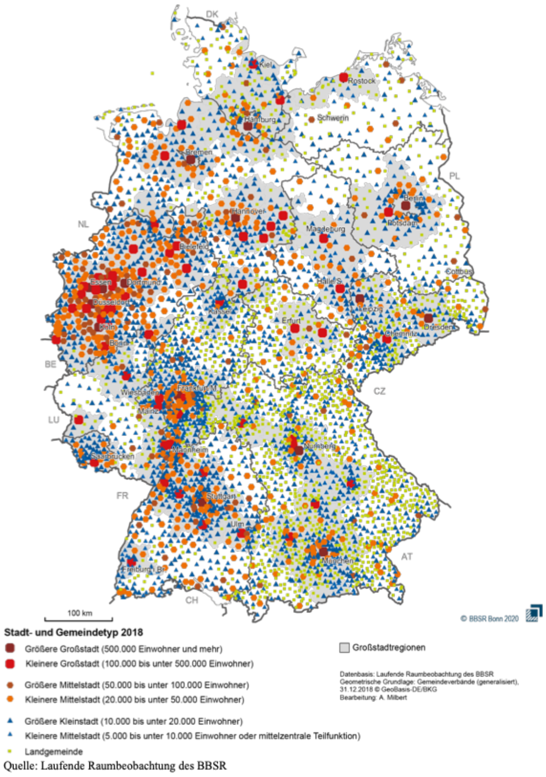
However, innovative activity is not homogeneous and randomly distributed across regions like the global population. Accordingly, companies that produce highly specialized technologies tend to locate close to others within the same industry sector, despite policymakers' efforts to diversify knowledge across regions and online in the ongoing trend of digitization and globalization (Asheim and Gertler, 2006). Regional innovation systems are, therefore, complex constructs that have been extensively researched. Many studies have shown that innovative behavior is more prevalent in urban areas than in less populated regions (Feldman and Audretsch, 1999; Berliant et al., 2006; Arbesman et al., 2009; Fritsch and Wyrwich, 2021b). In their study, Carlino et al. (2007) discovered a positive correlation between higher population density and increased patenting intensity per capita. However, cities are also associated with increased crime rates, traffic congestion, air pollution, and high living costs (Fritsch and Wyrwich, 2021b; Gertler et al., 2022). These downsides might be why some opt out to live in smaller cities, suburban or rural areas, and work remotely (Zenkteler et al., 2021). Accordingly, while many studies have demonstrated that cities exhibit higher overall productivity, this does not necessarily translate directly to innovation (Glaeser and Mare, 2001; Carlino and Kerr, 2015). *Innovation* is a dynamic process that can occur in various places and situations, as opposed to the more static nature of *productivity*. Consequently, recent studies have investigated the presence of innovators with new ideas in areas outside of metropolitan centers. Fritsch and Wyrwich (2021a) found that innovation can occur not only in large cities but also in rural areas through specialized clusters. This insight suggests that the role of cities in innovation may be overestimated Fritsch and Wyrwich (2021a). This dynamic raises the question of whether innovators move out of cities and whether and why innovative and entrepreneurship behavior occurs in non-metropolitan areas. These people might choose to work from home part- or full-time, as remote working is also evoked by the

COVID-19 pandemic and its various lockdown periods. Accordingly, mobility and transport accessibility become even more critical factors in this dynamic, as those who do telework also take further trips for recreational purposes in the time others spend on their commute (Moeckel, 2017).

Apart from people innovating in established companies, young firms or startups are additional crucial drivers of innovative behavior through their entrepreneurship and R&D activities (Acs and Audretsch, 1988; Schneider and Veugelers, 2010). Due to their crucial role in enhancing innovation and technological progress by developing radically novel products, newly founded firms are increasingly the focus of economic research (Haltiwanger et al., 2013; Pellegrino et al., 2012). A significant factor in the success of new firms is financial resources. Startups require external financial resources to invest in, among others, machinery, R&D, employees, and office space. Limited financing, therefore, can result in slower growth, underperformance, or even firm failure. Apart from private investments, public subsidy programs have been created to support young firms with high innovation potential in many countries. Most existing research shows that public funding positively affects company growth (Cantner and Kösters, 2015; Howell, 2017; Hottenrott and Richstein, 2020; Zhao and Ziedonis, 2020). However, it remains to be seen under which local conditions such programs are most effective. The location of the startup and program design may play a role (Hottenrott and Lopes-Bento, 2014). Some programs favor urban areas, specific regions, or target specific types of founders (Cumming et al., 2006; Kulicke, 2021; Rephann, 2020). The regional dimension of many programs is largely unexplored, as there are limited studies on where startup entrepreneurs found their businesses. It has been found that they cluster close to their friends and family, their Alma mater, or where they think financiers and corporate business partners are located (Stuart and Sorenson, 2003; Cooke, 2002; Feldman, 2004). This often occurs in cities with dense populations, where the transport infrastructure is developed; thus, where startups potentially see more benefits for their new company. However, the question remains whether this is the case or whether congestion effects and higher competition in urban areas negatively impact firms.

This dynamic is fascinating to analyze in countries that are structured in a more decentralized way, like Germany. Although cities there have been growing over the last decade, the country is relatively equally distributed in regards to infrastructure and population measures, like city sizes or distances to universities, schools, firm distribution, street network, and high-speed train stations (Fritsch and Wyrwich, 2021a). The underlying reasons for this are the historic federal structures that led to little dominating urban centers and many medium-sized cities (see Table A.0.1 for OECD definition of city sizes) in close proximity. This pattern can be seen in Figure 1.1[1], where all German cities are displayed with color-coding corresponding to their size; see Figure 4.1 for a map with names of the biggest cities. There are many medium- and large-sized cities in the mid-western part of the country, and the capital of Berlin is one big metropolis without many large towns or cities around it.

Figure 1.1: Cities in Germany Scaled to City-size



City-size in Germany in 2018 with dark-red dots for the biggest cities (above 100,000 inhabitants), smaller orange dots for medium-sized cities (above 20,000 inhabitants), and green dots for rural areas.

In the earlier days of the country, just before the 20th century, many decisions were made on a regional level, which led to decentralized settling. Federal governing tradition led to a quite even spatial distribution of regional banks, universities, and research institutions. The results of these settlement structures are that in under two hours by train or automobile, at least one larger city is reachable from anywhere in Germany (Fritsch and Wyrwich, 2018). Other European countries like France are structured more centrally, with the capital, Paris,

[1] Map provided by the Federal Institute for Building, City, and Spatial Research (BBSR): https://www.bbsr.bund.de/BBSR/DE.html.

as a major city for education, job opportunities, and a high mobility capacity. Of course, this exacerbates the adverse effects of metropolitan areas with high traffic congestion and competition for jobs. The question remains whether countries that are not centrally structured, innovative behavior can be found in smaller cities, suburban, or rural areas. In the United States, which is also decentralized, some outlier regions, such as Boston, Massachusetts, and Silicon Valley in California, are more innovative than others in a significant way (Agrawal et al., 2017). In the case of Germany, its business industry is essentially coined by small to medium-sized companies (SMEs), family businesses, or startups (Wolff et al., 2023). Furthermore, many *hidden champions*, thus companies that are national or international leaders in their industry field, but often unknown to the broader public (Simon, 2009), are located here. These firms of the so-called *Mittelstand* are usually family-owned, located close to their founding members, and never relocated to a more urbanized area (Vonnahme et al., 2018). Thus, they seem to strive without the advantages of agglomeration economies. For example, in the North-Rhine-Westphalia region, which takes a large part in the middle-western part of Germany, coal mining and an ample steel industry dominated the infrastructure until the 1970s (Fritsch and Wyrwich, 2021a). Although this is, accordingly, a heavily populated area, it is not as innovative as one might expect. More innovative areas are the Stuttgart area and the Munich urban zone, which display a higher level of innovative behavior per inhabitant (De Rassenfosse et al., 2013). However, a lot of innovative activity can also be detected between and outside of these metropolitan areas. In this dissertation thesis, it is, therefore, of great importance to look beyond regional population density and find out whether there are underperforming or overperforming areas in terms of innovation output and entrepreneurship behavior. As mentioned, this effect could be more pronounced in Germany than in more centralistic countries. This dynamic makes the research presented in the following three essays more relevant.

1.3 Theoretical Background

In this section, I will give the reader an overview of the literature on the economic part of this thesis and provide a detailed background on how innovation and accessibility are calculated since they are a vital part of all three studies.

1.3.0.1 Measuring Innovation and Entrepreneurship

In Chapter 2 of this thesis, the relationship between local accessibility and innovation activity is examined; in Chapter 3 and 4, I focus on entrepreneurial activity. However, quantifying innovation performance or activity can be challenging due to the multitude of variables representing *innovation*. A widely accepted definition of innovation is provided by Kline and Rosenberg (2010), who define it as introducing a novel product or production process or modifying, iteration, or enhancement of an existing product or process. Kline and Rosenberg (2010) further note that innovation is a non-linear process that involves iterations, feedback loops, and a learning process with multiple input points. This dynamic is supported by a statement from Acs and Varga (2002):

> *"Innovation is a matter of producing new knowledge or combining existing knowledge in new ways."*

Due to these various essential elements, measuring innovation can be difficult. Accuracy needs to be balanced against cost and time efficiency when selecting measures. Commonly used dimensions include patenting activity (applications, filings, or citations), scientific publications and their citations, skilled human capital, new product launches, or R&D expenditures (see Lanjouw and Schankerman, 1999; Berkes and Gaetani, 2021). Carlino and Kerr (2015) examine various methods for measuring innovation in academic research. They primarily focus on the patenting activity as an indicator of innovation, citing its frequent utilization in empirical studies. Patent data has several advantages as a measure of innovation, including its availability at a detailed geographic level and its ability to capture both the quantity and quality of innovative output. However, there are several limitations associated with patent data, such as the fact that not all innovations result in filed patents and that the propensity to patent varies across industries and over time. In addition to patent activity, other measures of innovation used in academic research include R&D intensity and productivity growth at the firm or regional level (Carlino and Kerr, 2015). In Chapter 2, I employ patent application data with inventor addresses to represent innovative activity in the area (De Rassenfosse et al., 2013). However, I enrich the patenting data by comparing it to a novel measure, the Predicted Innovator Probability (PIP), which uses information about a firm's innovation output derived from the firm's website text and analyzed using natural language processing techniques (Kinne and Lenz, 2021). This measure is introduced in-depth in Chapter 2 and can be used in future studies to indicate innovation.

Innovation is often associated with entrepreneurship. As such, studies have used entrepreneurial input and output as measures of innovative behavior at company, university, and regional levels. Entrepreneurship is an indicator that founders and firms are thinking innovatively. In Chapters 3 and 4, I examine local entrepreneurship activity by measuring the number of startups founded in a region, analyzing interviews with founders about their location choices, R&D, and innovative behavior, and examining how effective subsidies are in young firms. In Chapter 4, I additionally analyze data from the IAB/ZEW Startup Panel (Bersch et al., 2014), which provides information about startup and founder characteristics such as age, firm size, and industry sector, as well as R&D investments, profits, and patent output numbers.

Overall, these data sets provide detailed insights into individuals' and firms' innovative and entrepreneurial behavior.

1.3.0.2 Measuring Accessibility

One common variable I employ in all subsequent studies is transport accessibility. In the following three essays, accessibility concerns transport, mobility, and connectivity between locations for people. The concept of accessibility has been integral in the modeling and planning of spatial models over the past fifty years (Geurs and Van Wee, 2004). It remains the question of what accessibility exactly *is* and how it can be measured, since the accessibility of a region is contrary to an ideal situation not only determined by the mere distance or travel time between two locations, as Geurs et al. (2016) state:

> *"Accessibility can be viewed as a product of the land use and transport systems and describes the extent to which land use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)."*

Accordingly, not only travel times but factors like, for example, access to high-speed trains, frequency of buses, and the availability of bike paths play an important role and need to be considered when evaluating the accessibility of a location. Therefore, the accessibility estimation has to be tackled from different angles and by integrating a land-use model (Moeckel et al., 2018). According to (Geurs and Van Wee, 2004), defining accessibility can be achieved by including the following four components:

1. The land-use component includes the quality, the number of, and the spatial distribution of opportunities, such as shops, jobs, and health care facilities. Additionally, this contains information about the demand for these opportunities, as well as the

competition for them, such as Kindergarten spots and others.

2. The transportation component includes a time, costs, and effort element. It describes how people can get from A to B, how long it takes them (waiting, traveling, and parking), how much it costs them (variable and fixed), and which effort the travel takes (comfort level, reliability, risk of accidents, and others).

3. A temporal element describes the possibility or restriction to reach and use these opportunities at certain times. This aims at including, for example, rush hour times or less congested traffic on weekends.

4. An individual component describes a person's needs according to their personal background, like education, age, and others, and (e.g., physical) abilities, as well as personal opportunities, such as travel budget or income. These elements impact, for example, the accessibility to use a car as a transport mode or moving close to a better employment opportunity due to a certain socioeconomic status.

These four components need to be integrated when calculating the accessibility of a location. Accordingly, the dimensions have to be fixed spatially to the spatial zones in Germany. In this thesis, I introduce regional zones that have to be defined clearly as occasionally borders, spatial affiliation, or names of municipalities in Germany change over time. A, in spatial mobility research common, distribution of travel analysis zones is employed to establish the zone system in and around Germany in my studies. The transport accessibility used in this study is geographically based on these 11,717 zones that largely correspond to the municipality level. Additionally, the 14 biggest German cities (Berlin, Hamburg, Munich, Cologne, Frankfurt, Stuttgart, Düsseldorf, Dortmund, Essen, Leipzig, Bremen, Dresden, Hanover, and Nuremberg) are subdivided into smaller zones. For example, Munich is subdivided into around 30 zones, similar to the postal code division. This effort ensures that cities that are much larger in area size and inhabitant numbers with possible different accessibility values throughout the city are not averaged out. When taking all of this into consideration, concluding with a precise calculation of the transport accessibility for different modes of transport (car, long-distance rail, and short- and long-distance public transport) and taking into account potential congestion in high-traffic areas. The model distinguishes between different groups of travelers: the general population, the working population (human capital), and research workers.

The OECD definition of functional urban areas is applied in the upcoming studies, which defines a *city* as an administrative unit where half of its population lives in an urban center (OECD and Statistical Office of the European Communities, 2005). Figure A.0.1 in the Appendix section provides an overview of all accessibility values for a sample of 40 cities with four different city sizes according to the guidelines of the OECD and Statistical Office of the European Communities (2005). The table is color-coded depending on the accessibility value from zero (red) to one (green). From this overview, it can be retrieved that there are cities that have good accessibility for car travel but not for public transport and vice versa. Additionally, the overview hints that some places are on the smaller side population-wise but have, for example, higher accessibility to public transport than some metropolises. This suggests that accessibility is not only dependent on city size or population density.

It is important to note that local accessibility is influenced by the existing and developing transport system. It can, vice versa, impact land utilization and living costs in a region (Moeckel and Nagel, 2016). This relationship could, in turn, decrease the location's accessibility. Therefore, going beyond the mere value of travel times between zones is vital, making the upcoming economic calculations much more precise. The definitions and introduction to accessibility presented in this section are pertinent to subsequent chapters of this thesis. Furthermore, an in-depth description of the accessibilities of different transport modes can be found in Chapter 2. Chapter 3 discusses additional attraction factors for accessibility calculations, such as employee population.

1.4 Contribution and Findings

The insights that my studies provide contribute to the existing research on accessibility, innovation, and entrepreneurship. The research studies demonstrate that the innovation performance of a region indeed is positively impacted by local transport accessibility as better access to local and more distant knowledge increases innovative behavior in various contexts. This understanding is represented in a higher local patenting activity, a higher predicted innovator probability value, and increased startup numbers in better accessible locations. The effect can also be found in the essay in Chapter 4, which indicates that the receipt of subsidies has a higher impact on a startup's R&D externalities in accessible regions. These findings are new to the regional innovation literature. In this section, I will describe the underlying research questions and how I addressed them in each chapter individually.

1.4.1 Location-based Accessibilities and Innovation Performance

As previously stated, the importance of local characteristics for innovation activities has been studied extensively. However, it remains widely unknown whether and how congestion-impacted accessibilities affect the innovation performance of regions. Moreover, it is unclear to which degree congestion affects innovative activity and whether long-distance and local accessibilities play different roles. My analysis in Chapter 2 additionally aims to go beyond roads as well as cities as possible drivers of local knowledge flows. Therefore, I focus on this relationship by looking at the previously introduced transport accessibilities and how they impact local patenting activity and the predicted innovation probability.

The study builds on data from a Germany-wide agent-based transport model used to derive travel times and accessibilities for different modes of transport and accounting for road congestion. Besides geographical information drawn from patent application data, which is traditionally employed as an indicator of inventive efforts, this project makes use of novel innovation indicators based on website texts. Previous studies have in common that they rely on patented inventions as measures of innovation, which is enhanced by the novel innovation measure in the essay in Chapter 2. The patenting data is provided by the De Rassenfosse et al. (2013), which includes every recorded patent application worldwide from the years 1984 to 2014. However, in this study, I restrict the period of patenting from 2000 until 2014 to match the time of accessibility measurement more closely in time. The Predicted Innovator Probability (PIP) is measured by analyzing the texts of firm websites for their innovativeness. Using natural language processing techniques and averaging the firms' PIP score of every firm over their locational zone, Kinne and Lenz (2021) can predict the PIP for every zone in Germany. This measurement includes product and process innovation of the firm but also service offerings. I employ these measurements to investigate the role of accessibilities in local innovation activities. The overall research question in this essay, therefore, is: *Do locations that are generally more accessible perform better in terms of innovation than less accessible locations?* I estimate linear regression models in order to measure the impact of accessibilities on innovative local behavior. I do this for the modes of transport car (congested traffic and uncongested), long-distance rail, and local public transport (bus, metro, and tram). Additionally, I calculate the inter-dependencies between the transport modes to investigate whether they substitute one another. I also investigate if there are differences between the effects on patenting activity and the PIP by comparing regression results.

The results suggest there are both more inventive and more innovative activities in regions with better accessibility. These results hold up for both the patent applications and the PIP. This effect, however, reverses at very high accessibilities, indicating that the impact of accessibility on innovation reaches a plateau at some point. Additionally, the different modes of transport work as substitutes in this relationship. Although web-based innovation indicators appear to be positively correlated to patent measures, the correlation is not high. The former seems to be better suited than patent indicators to capture innovation activities in cities. The results based on patent data suggest that this may be related to local accessibility, which can be particularly good in rural, non-metropolitan areas. Providing new findings on the link between transport infrastructure and innovation, the results of this study underline that even in the digital age, the accessibility of locations seems to have an impact on innovation activity. These insights have implications for research on the geography of innovation and the development of measures for non-technological innovation.

1.4.2 Where Do I Even Start? Location Choice of Entrepreneurs and the Role of Transport Accessibility

Startup companies and their innovative products and services contribute to technological progress (Acs and Audretsch, 1988; Schneider and Veugelers, 2010). They also increase the competitive pressure on incumbents in their respective technology fields (Changoluisa and Fritsch, 2020) and directly and indirectly contribute to a region's economic development (Audretsch and Keilbach, 2004). Therefore, besides looking at patents and website texts as innovation indicators, researchers also looked at how entrepreneurial activity is impacted by location factors (Audretsch et al., 2012a; Capello, 2002; Huggins et al., 2017). However, it remains unclear to which extent better accessibilities influence the locational choices of young firms. In the second essay, I employ the priorly introduced accessibilities to investigate their role for entrepreneurs in choosing a place to start up their firm.

Young firms face other difficulties than established companies due to the nature of starting out (Cassar, 2004). When they begin to establish their ideas, one of the first vital actions is finding office or production spaces. This decision also influences whether firms find qualified personnel, efficiently acquire production materials, and distribute products and goods among customers to their liking (Audretsch and Dohse, 2004). The second essay in this thesis targets the understanding of the location decision of startups and how the perceived accessibility of a location might impact founders. The study consists of a quantitative part where I look at startup founding rates in Germany and estimate ordinary least-squared regression models to understand the relationship between the accessibility of a municipality and its impact on the local startup founding rate. In this essay, I make use of the previously introduced accessibility measurement for the 11,717 micro-geographic zones within Germany but enhance this with another in-depth measurement. The accessibilities can be calculated for different population groups or attraction factors. Accordingly, the attraction factor in this study is not only the general population as in Chapter 2, but further I employ the population of human capital and of employees at research institutions and universities. These different kinds of populations provide insights into how the availability of human capital factors in the location of startup firms. This pattern is grounded in the fact that startups usually need highly skilled knowledge workers to conduct research and develop novel products. I, therefore, hypothesize that founders value accessibility and cluster in better accessible locations. Thus, I expect that in locations that are generally more accessible, more startups are founded, and this effect is even more pronounced for local human capital and research workers. In order to undertake this analysis, I use startup founding rates stemming from the Mannheim Enterprise Panel (MUP) provided by the ZEW (Center for European Economic Research). Using this data from 2000 until 2019, I estimate regression models to investigate the link between a location's accessibility and the number of startups founded in the same analysis zone. In the second part of this essay, I further investigate how founders undertake a location decision and evaluate interviews with startup founders on their location decision, which variables factored into that decision, and what impacts it had on their business endeavors.

The quantitative regression results suggest that there is indeed more startup founding activity in regions with better accessibility. The results also indicate a slightly higher and statistically significant regression coefficient for the employee population. This insight underlines that especially human capital plays a distinct role in the early days of new companies. This is unexpectedly only the case for the entire employee population and not for research employees, as this regression coefficient is significant but lower than for the other population groups. These insights are also underlined by the qualitative data, as the accessibility of a region seems to be of great importance for founders. They connect accessibility to the better availability of qualified workers and transportation cost minimization in more accessible regions. Accordingly, accessible regions are more attractive to founders for their commute, and they also expect their hiring strategies to be more successful when potential employees can reach their startups easily. The results from this study have implications for research on transport accessibilities, where founders start up a company, and which methods they employ compared to established firms. The insights of this research are also attractive to founders on where to locate a startup company. Thus, these results indicate that accessibility is of value for both innovation and entrepreneurship.

1.4.3 The Role of Location-based Accessibility for the Effectiveness of Startup Subsidies

As mentioned previously, startups face a multitude of challenges related to the liability of newness (Cassar, 2004). This is not only limited to the location of a new firm but might be impacting the effectiveness of startup subsidies in the respective young firms. Public policies aim at providing support, for example, through startup subsidies to overcome early-stage financing constraints hampering firm developments, research investments, and survival. As some literature sources show, these subsidies usually positively impact a startup's development (Cantner and Kösters, 2015; Howell, 2017; Hottenrott and Richstein, 2020). It, however, remains largely unknown to which extent better accessibilities influence innovation in young companies, as literature on the topic is still scarce.

In the study in Chapter 4, I investigate how a startup's location influences the effectiveness of public support in the form of subsidies. Based on insights from previous research, I set up two opposing hypotheses: The first is based on the idea that startups in less accessible places have a higher need for support because their location provides less infrastructure and fewer knowledge spillovers. Public support may be more effective since the constraint is more binding, and hence, there is more potential to be uncovered. Moreover, better accessibility may come at the cost of higher competition for resources and, therefore, higher costs, including for renting and wages (Gertler et al., 2022), which may make expanding business activities in response to subsidies less costly and more feasible in less accessible locations. Therefore, I first hypothesize that the treatment effects of startup subsidies are more prominent in less accessible locations (Need Hypothesis). On the other hand, startups may be able to make more effective use of subsidies in better accessible locations because they provide complementary infrastructure and resources. Moreover, there may be better opportunities in more accessible places concerning collaboration and exchange with other organizations. Perhaps most importantly, better accessibility, as I define it in this study, means better access to human capital and customers. Therefore, I hypothesize that the treatment effects of startup subsidies are higher in better-accessible locations (Opportunity Hypothesis).

For the empirical investigation, I again utilize the nuanced measure of accessibility, including car transport, public transport, and trains. Like in Chapter 3, I derive distinct measures of a location's potential accessibility based on whether I aim to capture its accessibility to the general population, the workforce (employees), or R&D employees (employees engaged in research-related occupations). Additionally, given that potential accessibility may be overestimated in zones with greater opportunities (i.e., possessing higher attractiveness) due to increased competition for these opportunities, I employ competitive accessibilities that discount locations with heightened competition between seekers of these opportunities. I integrate these indicators with data from newly established firms surveyed via the IAB/ZEW Startup Panel (Fryges et al., 2009) for regression analysis. To investigate my research interest, I initially calculate the average treatment effects of receiving startup support utilizing econometric matching techniques that account for the highly selective nature of subsidy awards. Specifically, this replicates the analysis conducted by Hottenrott and Richstein (2020) using an updated and expanded sample of German startups. Subsequently, I undertake a treatment effect heterogeneity analysis to investigate whether the magnitude of individual treatment effects is contingent upon the accessibility of a startup's location (Hottenrott and Lopes-Bento, 2014; Hottenrott et al., 2017). The findings confirm that there is indeed a positive average treatment effect of public subsidies on various outcomes, including R&D spending, investment, revenues, innovation, and survival. However, I only observe a minimal significant impact of accessibility on most of these outcomes. Nonetheless, startups situated in locations with higher accessibility to R&D employees and more competitive accessibility exhibit greater additional R&D efforts (expenditures and R&D employees) and an increased likelihood of innovating in response to public support. Thus, the results indicate that subsidies elicit higher additional R&D investments when startups have enhanced access to potential (R&D) employees. This understanding suggests that improved accessibility, particularly for the R&D workforce, indeed augments the effectiveness of startup subsidies. For non-R&D-related outcomes, local accessibility does not appear to influence the magnitude of the treatment effect.

This study's findings provide a significant addition to the current body of research regarding the utilization of startup subsidies as a tool for fostering innovation. The results suggest that accessibility is a key factor concerning R&D input additionality. However, location-based disparities were not observed for non-R&D inputs, short-term growth, or firm survival. These observations are consistent with those of Rammer et al. (2020), who similarly found no substantial evidence of regional influences on the effectiveness of government subsidies. By explicitly examining young firms, which are instrumental in driving innovation and regional development (Haltiwanger et al., 2016; Schneider and Veugelers, 2010), my study adds to the existing literature. Consequently, the findings have significant policy implications: investing in new firms in regions with greater access to highly skilled human capital could yield higher returns on investment in additional R&D within the region. This dynamic could also be seen critically, as this would encourage giving subsidies to urban environments rather than to rural areas. However, accessibility is still a critical factor here, so increasing transport accessibility in rural areas could also bring the intended effect.

1.4.3.1 Private Investments and Their Impact on Local Education and Innovation Ecosystems

Another study of mine that is not part of this thesis but is closely related provides additional insights into innovation ecosystems and location factors (Rentrop et al., 2023). As stated in the previous section, local innovation, and entrepreneurship behavior seem influenced by startup subsidies and locational factors, as (regional) public subsidies often support startups and universities to enhance innovative behavior (Hottenrott and Richstein, 2020). In some cases, private foundations also subsidize a specific region, for example, when a private donor is connected to an area and wants to support it (Haddad, 2021). Thus, concluding from existing literature, it remains unclear whether and how the local innovation and university ecosystem is influenced by (a) a shock to the established system by significant financial investments and (b) existing regional characteristics.

This project is joint work with Cindy Rentrop, Kashina Perlinger with the working title *Private Patrons - Big Impacts? How Private Investments Shape Education and Innovation Ecosystems*, a quantitative and qualitative study is conducted to investigate a unique research case. We looked at how an established entrepreneurship and educational ecosystem in a medium-sized southwest German city characterized by hidden champions and the *Mittelstand* (Simon, 2009) is impacted by significant investments of a private donor into the region in 2011. As these investments by the donor, who has a personal connection to the area, were quite steep, they presumably impacted the local innovation and entrepreneurship activity and the local educational landscape. The investments financed an educational campus with a new branch of an established international university, a programming school, a private high school, and an entrepreneurship center to enhance the region's national and international visibility. For the quantitative part of the study, we employed coarsened-exact matching techniques based on local economic characteristics to build up a database of our target region and comparable regions. We applied this to compare economically, inventively, and educationally positioned regions similar to our target location but did not receive the investment treatment. Then, a difference-in-differences analysis of our target region before and after the investment treatment was performed. In particular, we investigated how these actions impacted, among others, local patenting activity, the number of startup companies, and the number of university publications for our quantitative study part. For the qualitative part, local industry stakeholders, university experts, and inhabitants of the study region were interviewed on how they evaluate the actions of the private donor.

Despite the steep investments in the area, we could not yet detect any significant changes in the region's educational and entrepreneurial capacity apart from an increased number of graduate students. This result suggests that more actions are necessary to make this location more known to national and international talents. The interview results, however, indicate that the changes were already noticeable in the socioeconomic structure and people's minds. According to the interview partners, the new predominantly international students that attend the novel university branch might need to be integrated better to work in the local SMEs. Founding companies and conducting innovation is also challenging when having to establish a support network from scratch. The fit between the existing innovation, entrepreneurship, and educational system and the establishment of new educational and startup facilities might not (yet) be exact. Therefore, the interview partners were hesitant to call the investments into the region a success. When looking at the accessibility of the study area, it is already relatively high for the general population and (research) employees for all modes of transport. Although accessibility was not part of this study, this could also be further investigated in future analyses. This study has implications for understanding how large private investments stemming from a personal connection impact local innovation, entrepreneurship, and education. The insights of this study are essential for investors and local policymakers on how to bring together existing and new structures.

1.5 Thesis Outline

Following this introduction to the topic of transport accessibility and its role in economic performance and entrepreneurship, Chapters 2, 3, and 4 dive into the specific relationships between these measures. The chapters are individually introduced and concluded, thus self-contained. Chapter 2 includes an in-depth introduction to transport accessibility for the general population and how it impacts local innovation activity. As Chapter 3 also includes different attractors for accessibilities, it carries a detailed description of these different accessibility calculations. This essay is about how accessibility impacts the location choice of entrepreneurs. Chapter 4 is about how accessibilities impact the effectiveness of startup subsidies. Following Chapter 4 is a conclusion and summary of the main insights and an outlook on future topic opportunities.

2 | Location-based Accessibilities and Innovation Performance

2.1 Abstract

While the importance of local characteristics for innovation activities has been studied extensively, it remains largely unknown to which extent better transport-based accessibilities facilitate innovation. This study builds on data from a Germany-wide agent-based transport model used to derive travel times and accessibilities for different modes of transport and accounting for road congestion. We employ these accessibilities to investigate their role in local innovation activities. Besides geographical information on inventive activity drawn from patent application data, which is traditionally employed as an indicator of inventive efforts, this project makes use of novel innovation indicators based on website texts. The results suggest there are both more inventive and more innovative activities in regions with better accessibility and that different modes of transport work as substitutes in this relationship. Web-based innovation indicators appear to be positively correlated to patent measures, but the correlation is small. The former appears to be better suited than patent indicators to capture innovation activities in cities. The results from this study have implications for research on the geography of innovation and the development of measures for non-technological innovation.

2.2 Introduction

Innovation has long been found to be an important driver of regional competitiveness and growth (Audretsch and Feldman, 2004; Frenkel and Shefer, 1996), and location factors have been shown to facilitate firms' innovation performance (Frenkel and Shefer, 1996; Harhoff, 1999). More innovative activities have also been linked to increases in local living standards (Grossman and Helpman, 1994).

Author contributions: This chapter is joint work with Hanna Hottenrott.

Previous research focused on why some regions perform and develop better than other regions. Locational differences include the impact of access to employees, agglomeration benefits, and access to financing or subsidies (Feldman, 1994). These factors can explain why we observe more innovation in some regions as a result of knowledge spillovers as well as through the presence of large knowledge producers like universities (Czarnitzki and Hottenrott, 2009). Knowledge transfer can be facilitated through research institutions, qualified and specialized human capital, as well as customers, suppliers, competitors, and possible collaboration partners (Hottenrott and Lopes-Bento, 2015; Fudickar and Hottenrott, 2019). Researchers also found that companies try to locate in close proximity to similar companies in order to use the established social and professional links (Stuart and Sorenson, 2003). Already in Roman times, establishing transport routes led to denser trading networks and continues to influence economic interaction today (Flückiger et al., 2022). Many studies emphasized the positive enhancer role of densely populated areas, such as cities, in innovation production (Berliant et al., 2006; Carlino et al., 2007). Innovation research, therefore, emphasizes the impact of location factors that facilitate knowledge spillovers or transfers and their role in innovation activities.

However, research on the degree of multiplier effects or congestion generated by local characteristics, network effects, and particularly transport accessibilities is still scarce. In this study, we aim to contribute to this research by investigating the link between local accessibilities and innovation performance at a micro-geographic level. Better access to local and more distant knowledge has been shown to facilitate innovation in different contexts. This study, therefore, builds on the few central studies on this topic. Fritsch and Wyrwich (2021b) focus in their study on agglomeration economies covering selected OECD countries and conclude that the role of big cities as hubs of innovation activity might be overemphasized. According to their research, patented inventions are distributed across bigger cities as well as rural areas. They found only two countries where patenting activities seem to be concentrated in metropolitan areas: South Korea and the United States. Using patent inventor addresses, population density, and urban area data, they calculated the share of patent inventors per inhabitant in an area. This way, they could compare the patents per population ratio between urban and rural regions to compare population density and population size. Comparing the number of inventors and the number of patents in a region, they find inventors seem to be only slightly more productive in cities across the United States, South Korea, and Italy, but not elsewhere. Shearmur (2012) found that innovation that seems to be marketed predominantly in cities is often produced outside urban areas.

In a related study that focuses on Germany, Fritsch and Wyrwich (2021a) likewise show that the common assumption that innovation happens mostly in larger cities is not generally valid. In their study, they show that innovation is not concentrated in metropolitan areas but also in smaller cities that are in proximity (reachable within one to two hours) to larger cities. Counting headquarters of 1,700 firms that they classify as *hidden champions* in Germany, they find that only 26% of these firms are in large cities, 36% in medium-sized towns, and 37.5% in small towns. To investigate where innovation is happening, they analyze the number of patents per inhabitant, the number of R&D employees, and the number of businesses in the manufacturing sector. They find that the distributed locations of publicly funded universities, universities of applied sciences, and research organizations can explain why they find these relatively even distributions of firms across cities of different sizes since Germany's educational system is also relatively decentralized. Fritsch and Wyrwich (2021a) conclude that the factor providing a suburban advantage lies within tacit knowledge passed down from generation to generation. As the authors argued in an earlier essay (Fritsch and Wyrwich, 2018), a significant part of the relevant knowledge for innovation activity is of tacit manner, i.e., it is connected to people and, therefore, regionally bounded. This dynamic implies that due to the stickiness of tacit knowledge, it tends to stay local but can be passed down through generations. Conclusively, the infrastructure, education system, and firm structure in Germany historically appear more decentralized than in other economies, leading to a lower concentration of innovation activity in large cities. Nevertheless, the authors also stress that the characteristics of smaller cities support this, while it remains unclear whether the nature of innovation differs between metropolitan and other regions.

The type of innovation that is generated in different locations is the subject of the study by Berkes and Gaetani (2021). The authors investigate US patent data and find that inventions in urban areas with a highly dense population are more atypical than in other regions as they receive more citations outside of their technology class. In low-density regions, however, clusters emerge that are more specialized in specific technologies. Berkes and Gaetani (2021) focus on the network of patents within a region that proxy for between-area idea flows. Patents that form more citation pairs are more conventional, and patents that are distributively cited by several different patents are defined as more unconventional. They also measure in-region patent citations based on inventor addresses and assign a score to patent citation pairs on their conventionality. They conclude that the density of an area affects the type of inventions rather than the number alone. Technological diversification is also found more strongly in high-density areas compared to low-density areas.

Likewise, Agrawal et al. (2017) stress the role of inter- and intra-regional knowledge flows. They find transportation infrastructure to play a crucial role in innovation as it facilitates the mobility of human capital and the flow of goods. In particular, they find that a 10% increase in 1983 highway kilometers leads to a 1.7% rise in the number of patents in a five-year window and more essential inventions, measured by citations to these patents. The authors address the challenge that transportation infrastructure emerges as a result of innovation activity by utilizing historical highway plans. Agrawal et al. (2017) thereby go beyond the flow of human capital into cities, known as agglomeration economies, which has been covered in regional innovation literature extensively (Black and Henderson, 1999; Glaeser and Gottlieb, 2009). To measure innovation, they use patenting counts and patent citation data mapped to US metropolitan statistical areas (MSAs). They exploit patent citation links to quantify local knowledge flows. For each patent in a region, they calculate the distance between the location of the inventor of the focal patent and the location of the inventor(s) of patents cited by the focal patent in the same MSA and then compute the average distance in an MSA. The finding that an increase in highway kilometers results in more distant citations suggests that transport infrastructure facilitates knowledge flows over longer distances. This insight aligns with results by Roche (2020), who finds that the physical layout of cities in the US affects innovation by influencing the organization of knowledge exchange. In particular, variation in street network density explains regional innovation. Additionally, the study by Ejermo et al. (2022) shows that a new bridge between Swedish Malmö and the Danish capital Copenhagen significantly affected innovative efforts in the region of Malmö measured by the number of patents per individual. The authors argue that the critical mechanism driving this effect is the attraction of highly qualified workers to the Malmö region following the bridge's construction.

These studies provide an essential basis for our analysis which aims to go beyond roads as a possible driver of local knowledge flows. In doing so, we look at accessibilities that include car travel, local public transport (bus, metro, tram), and long-distance train transportation. Previous work led to valuable insights and points to several puzzling coherences. First, previous research seems to suggest that accessibility is crucial for innovation (Komikado et al., 2021), yet other studies find substantial innovative activities outside of cities (Fritsch and Wyrwich, 2021b). All previous studies have in common that they rely on patented inventions as measures of innovation. Moreover, to which degree congestion affects innovative activity remains largely unexplored, and whether long-distance and local accessibilities play different roles. Therefore, we investigate whether accessibilities impact innovation by using a country-wide transport model to derive travel times and calculate accessibilities. Our analysis focuses on the level of Germany-wide zones and comprises accessibilities for different modes of transport and uses a different approach for modeling congestion. In the subsequent analysis, we employ these accessibilities to investigate their role in local innovation activities. Besides geographical information drawn from patent data, which is traditionally employed as an indicator of inventive efforts, this study anaylizes website texts to generate a novel innovation indicator based on natural language processing techniques Kinne and Lenz (2021).

The chapter is structured as follows: First, we describe the primary measures used in the analysis. We describe the calculation of accessibilities based on an integrated land-use transport model (Geurs and Van Wee, 2004) and the measures for innovative activity. Second, we derive a set of hypotheses to be tested empirically. Next, we describe the data and method in more detail. Finally, we present and discuss the results.

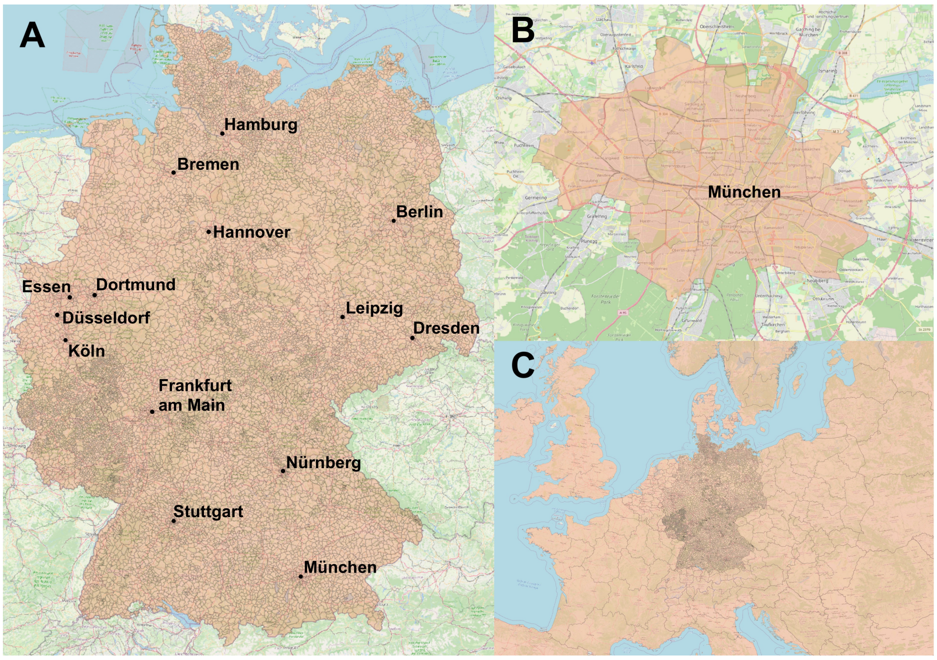
2.3 Measuring Accessibility

We use a country-wide transport model to calculate travel times and accessibilities and an agent-based modeling approach allows taking multi-modal traveling demand into account. We divide Germany and its neighboring countries into micro-geographic zones for our study. Within Germany, the zones correspond largely to municipalities, with the 14 most populated cities in the country split into smaller zones at the borough level. This results in a study area consisting of 11,717 zones (Figure 2.1 [A] and [B]).

In addition, we include all neighboring countries at a lower resolution level to capture cross-border accessibility resulting in a study area of 11,879 zones (Figure 2.1 [C]). To estimate freeflow travel times between the study area zones, we use information about the transport network (streets and railroad). The transport network consists of local public transport which includes busses, trams, and subways; long-distance busses; and the long-distance train network (sub-urban train, regional and high-speed rail)[2]. The local public

[2]This information stems from several sources: OpenStreetMaps (https://www.openstreetmap.org), GTFS (https://gtfs.de), and Openflights (https://openflights.org). See detailed Figure A.1.1 in the Appendix.

Figure 2.1: Study Area Germany



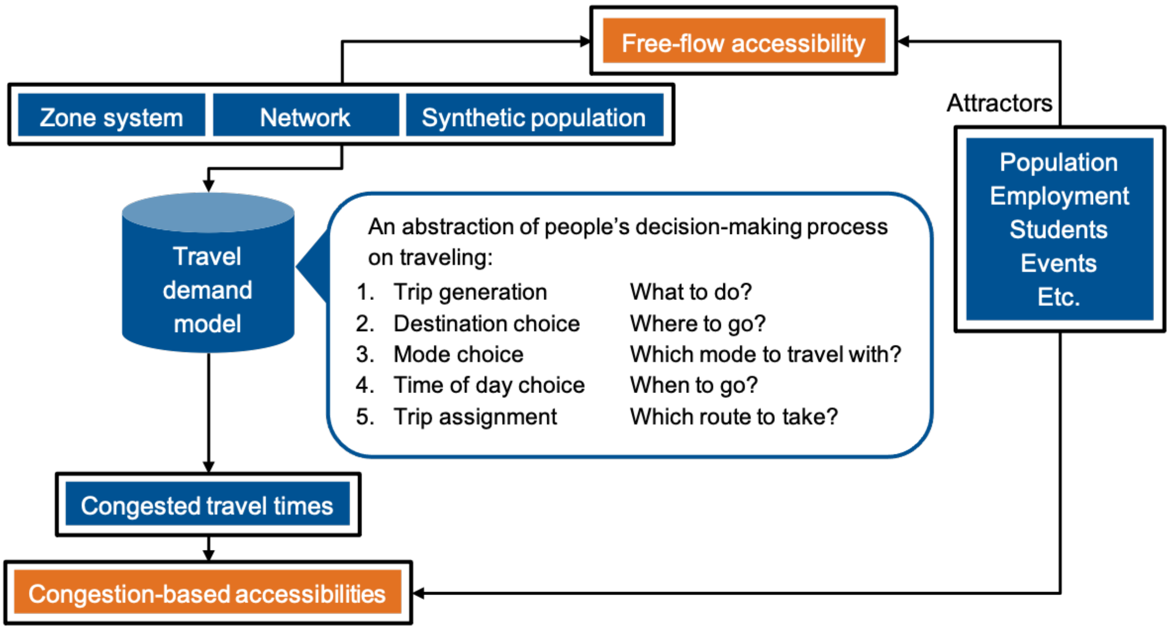
Study area (A - zones within Germany at municipality level, B - zones within Munich at borough level, C - complete study area).

transport modes are used as access and egress points for the long-distance modes. We set up a threshold of 40km to distinguish between short- and long-distance trips. This long-distance model follows a modeling approach comprising trip generation, destination choice, mode choice, time of day choice, and trip assignment (Figure 2.2).

At first, agents decide whether to take a trip and to which destination. Then, they decide on the mode which provides the shortest route. These steps of the model are estimated based on travel behavior captured in a nationwide travel survey by the Ministry of Transport and Digital Infrastructure (Federal Ministry of Transport and Digital Infrastructure, 2017). This survey has been conducted every five to nine years since 1970, and it includes socio-demographic information of the respondents within different population groups and regions, as well as information regarding the trips the respondents made. We use the 2017 travel survey as a basis for the trip simulation, although modified patterns tend to be relatively constant over time. This information is used to construct a synthetic population based on which the trips can be simulated.

Using the complete transport network, we calculate travel schemes which include the information about travel times between all the zone pairs by different travel modes (Pukhova et al., 2021). The resulting value provides information about the freeflow uncongested travel

Figure 2.2: Accessibility Modeling Approach



Adapted from Moeckel et al. (2020).

times between all zones.

To estimate travel times considering the traffic flow on the network for the route choice (Traffic Assignment), we use Multi-Agent Transport Simulation (MATSim) (Axhausen et al., 2016). This results in information on congested travel times, taking into account the number of agents picking a particular route.

Based on these travel times, we can calculate the accessibility of any of the zones as:

$$Potential\,accessibility_i = \sum_{j=1}^{n} D^{j^{\alpha}} * e^{-\beta * tt_{ij}} \tag{2.3.1}$$

where:

D is the attraction factor or the number of opportunities at destination zone j,

tt_{ij} the time of travel between zones i and j,

α describes the weight placed on the attractor,

β the time-sensitivity parameter; the higher the β the more are longer travel times penalized.

The resulting accumulated accessibility using the population as an attraction factor (with parameters $\alpha = 1.0$ and $\beta = 1.0$) is presented in Figure 2.3. The map on the left-hand side shows freeflow car accessibilities while the right-hand side illustrates congested car accessibilities. Congested car accessibility is the more realistic measure, as there is always some congestion due to sticky road construction and capacity limits. The difference between the two measures is particularly strong within larger cities and in regions in the west and southwest of Germany where congested car accessibilities are much lower than in freeflow traffic. As an example, the accessibility of the Munich city center is 0.62 for local public transport (local BMT), 0.44 for freeflow car, 0.41 for congested car, and 0.49 for long-distance rail. Munich has around 1.47m inhabitants. Hanau, with 98.502 inhabitants a medium-sized city, has freeflow accessibility of 0.63 and 0.61 for congested car, as well as a local BMT accessibility of 0.35 and long-distance rail accessibility of 0.62, probably stemming from several daily fast train connections (InterCityExpress train). As a comparison, a small town called Marsberg with 20.993 inhabitants, has a local public transport accessibility of 0.03, 0.56 for freeflow car, 0.55 for congested car, and 0.09 for long-distance rail. Just as expected, it seems that although Munich is quite accessible by local public transport, the car accessibility is lower than the one of a small town and even lower when there is congestion. An overview of accessibility values can be found in Table A.0.1 for ten cities in each category of OECD urban center size. The ten cities are the largest ones either in the range of 50000-100000 inhabitants (size S), 100000-250000 inhabitants (size M), or they are one of the ten smallest and ten largest cities in Germany; reference point is the year 2021[3].

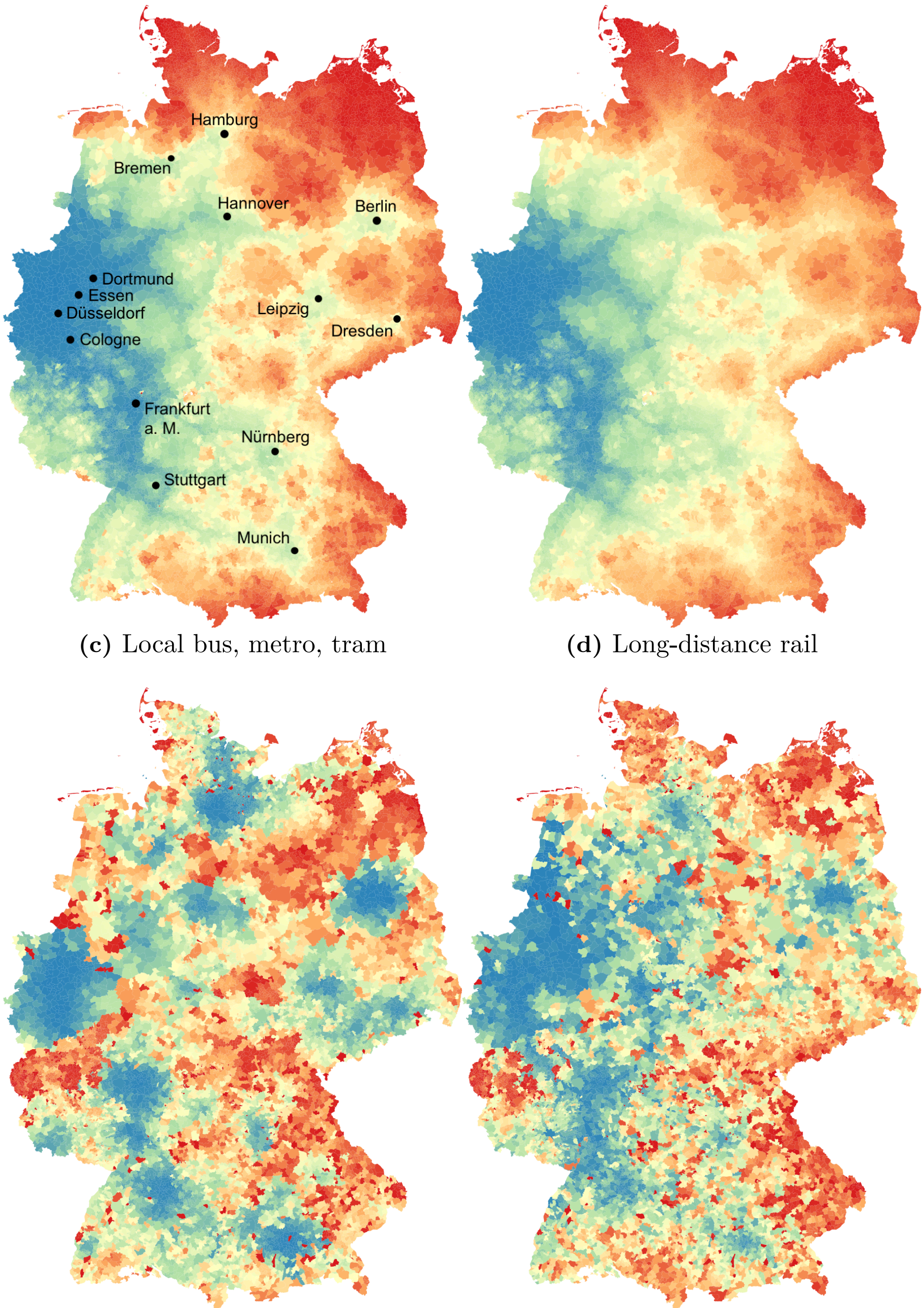
Figure 2.4 shows the density distributions of the four main accessibilities. While car accessibility and congested car accessibility are more evenly distributed, long-distance rail and especially local BMT are skewed towards lower accessibilities.

[3]Information retrieved from https://destatis.com. Last accessed on 31.05.2023.

Figure 2.3: Accessibility within Germany with the Population as the Attraction Factor

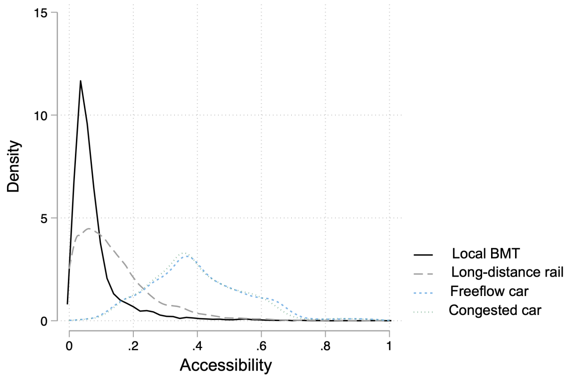
(a) Car congested **(b)** Car freeflow

(c) Local bus, metro, tram **(d)** Long-distance rail



Accessibility weights at $\alpha = 1.0$, $\beta = 1.0$. Scaling color gradient: Blue = high accessibility (1); yellow = medium accessibility; red = low accessibility (0).

Figure 2.4: Density Distribution of Accessibility Scores



2.4 Measuring Innovation

We measure innovation using two different approaches. The first is based on patent data which is traditionally and frequently used in innovation studies. The second consists of a novel innovation indicator based on textual data and natural language processing (NLP), which provides innovation information for firms.

Innovation activities are often measured using patent data, although patents relate to inventions, not products. Still, patents are a helpful indicator as new products, particularly radically new products, typically rely on new inventions or inventive parts and components. Moreover, patents are a readily available and standardized source of information, making patent data an essential indicator for inventive activity (De Rassenfosse and Zhou, 2020). A significant advantage of using patent information as an innovation indicator is that patent documents identify the location of the inventor(s) and the patent owner. This dynamic facilitates precise analyses of the geography of an invention; see Agrawal et al. (2017) or Berkes and Gaetani (2021) for recent examples. The data used in the following study is provided by De Rassenfosse et al. (2019) and contains patent applications (invention patents), including geo-coded addresses of inventors from 1984 to 2014. We restrict the period at the lower bound to 2000-2014 and take the sum of patent applications as the primary indicator. The patent information includes patents recorded in the PATSTAT database of the European Patent Office, as well as information from nine national patent offices. We include every application regardless of its granting status. This inclusion ensures that inventive activity is recorded independent of strategic delays that may affect the grant date. We consider each inventor as a separate unit so that, for example, a patent application with three inventors provides three addresses. The data comprises 665,775 different patents with 1,5M inventor applications. We assign inventors' addresses to the zones based on each inventor's exact address, which provides a complete map of patenting activity in Germany[4].

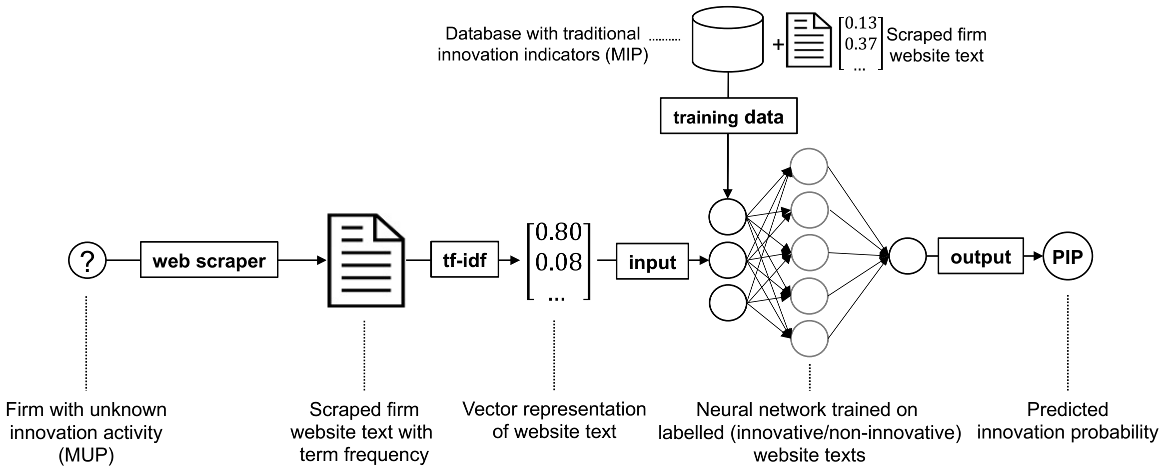
The Predicted Innovator Probability (PIP) is constructed based on a method developed by Kinne and Lenz (2021). The key information for constructing the PIP is companies' website texts crawled from 2018-2020. Websites are linked to company data using information from the Mannheim Enterprise Panel (MUP). The MUP covers the universe of companies located in Germany and is constructed using data from the official business registry, and contains more than three million firms. For a subset of these companies, the Mannheim Innovation Panel (MIP) provides survey data collected through an annual survey focused on firms' innovation activities. The survey is part of the EU's Community Innovation Survey (CIS), which follows the innovation definitions from the Oslo Manual (OECD and Statistical Office of the European Communities, 2005). The relevant information for this study is whether firms introduced new products or services in a given year. The focus on product (and service) innovations rather than process innovations is plausible, given that they are more likely to be represented on a firm's website. Using the MIP survey information, a training data set was created for an artificial neural network (ANN) to distinguish between innovative and non-innovative firms using natural language processing (NLP) on the firms' website texts. To predict a firm's innovation probability, the ANN categorized website texts as either innovative or non-innovative and calculated a predicted innovation score based on the text analysis results for all firms in the MUP (with a website). See Figure 2.5 for an illustration of the PIP generation and Kinne and Axenbeck (2018) for a detailed description of the website text preparation. According to Kinne and Lenz (2021), the method provides an 81% precision for the innovative class and the overall f1-score of the model is at 80%. Comparing the PIP with the survey-based innovation status shows that the classification is rather conservative by classifying firms as too ordinary or too innovative (except for firms active in information, technology, and communication (ICT) services). Rammer and Es-Sadki (2023) argue that these kinds of big data methods for innovation prediction can efficiently enhance traditional measures.

The PIP has been calculated for 9.913 of the 11,717 zones in Germany, which equates to 91.7%. The missing municipalities have an insufficient number of companies with available websites (Kinne and Lenz, 2021). We aggregate firm-level PIP scores to the accessibilities' zone level based on firms' addresses as recorded in the MUP. This provides us with an

[4]Note that we assign the same weight to each inventor on a patent. That is, a patent co-invented by inventors located in different regions is counted as many times as there are inventors listed on the patent.

essentially complete map of innovation activities as measured by the PIP for Germany, as seen in Figure 2.6. Moreover, we can distinguish between a PIP aggregated by groups of firms, such as their sector of activity, size, and maturity stage.

Figure 2.5: Firm Innovation Prediction Model



Adapted from Kinne and Lenz (2021).

2.5 Research Question and Hypotheses

The fundamental research question that the following analysis aims to address is whether and to what extent regional innovation activities can be linked to the region's accessibility. Previous research linking regional characteristics and innovation performance long suggested that location matters (Frenkel and Shefer, 1996; Stuart and Sorenson, 2003; Harhoff, 1999; Czarnitzki and Hottenrott, 2009). Recent research on the geography of innovation investigated traffic infrastructure and its role in innovation as well as differences in the nature of innovation depending on the location (Agrawal et al., 2017; Berkes and Gaetani, 2021; Fritsch and Wyrwich, 2018, 2021a, 2021b). This understanding confirms these earlier insights and, in addition, suggests that accessibilities play a critical role. Moreover, Rammer et al. (2020) stress that even in times of increased digital communication, local knowledge spillovers enhance regional innovation activity but that it requires close proximity. Spillovers strongly decreasing within a few meters indicates that location may still be of high importance for innovation and that an urban/non-urban dichotomy may be insufficient to assess the impact of the degree of regional accessibility on innovation.

Earlier research also suggests that it is, in particular, the access to human capital that matters for innovation performance (Czarnitzki and Hottenrott, 2009). This introspection includes how a region is connected to potential employees as well as to potential customers or collaborators (Audretsch and Feldman, 2004). Nevertheless, it remains vastly unexplored whether and how accessibilities (and hence congestion) affect the innovation performance of regions, especially using measures for innovation that also capture non-patentable inventions as well as new products and services.

To investigate this question, we build on established as well as the previously introduced novel innovation indicators and multiple measures for accessibility. This allows us to explore heterogeneity in terms of the type of innovation and the way through which accessibility is achieved. However, research on individual mobility differentiating between (local) public and car transport is scarce. Employees may prefer car commutes without sufficient local public transport or vice versa if roads are congested by traffic. It is, therefore, crucial to consider multi-mode accessibility. We differentiate between local public transport (bus, metro, tram), long-distance transportation (rail), and individual mobility (car). All of these modes of transportation could play a role in the innovation performance of firms in regions as well as in the location of inventors. Local transport facilitates the commuting of employees, and greater accessibility of an employer could mean that the company has better access to human capital (in terms of quantity but also qualification). Moreover, better accessible locations may also be beneficial in terms of suppliers providing easier access to non-human resources. Finally, better local accessibilities could facilitate sales and hence provide incentives for innovation. Similarly, accessibility by car can be important for commuting as well as for logistics but may be subject to congestion due to traffic. In particular, within larger cities, car accessibility may differ from accessibility by bus, metro, and tram (BMT). Accessing specific locations by car may even be impossible, given the lack of roads or parking. On the other hand, BMT accessibility may deteriorate strongly towards periphery locations. The differentiation between local accessibility and long-distance accessibility is furthermore vital as long-distance connections can facilitate access to a much larger population which may affect both the human capital channel as well as the business channel (suppliers/customers).

Based on insights from previous research, we, therefore, hypothesize that:

Hypothesis 1: *Locations that are generally more accessible perform better in terms of innovation than less accessible locations.*

Although we expect a positive and significant correlation between any type of accessibility and innovation, the additional gain from being at a highly accessible location may decline at a certain level of already good accessibility. That is, the difference in innovation performance between a low-accessible and median-accessible location should be more prominent than the difference between a median and a highly accessible location. As argued above, commuter accessibility and local public transport should matter because they connect employers and employees. In addition, in consumer-oriented sectors, these modes of transport are relevant from a demand perspective. While potentially meaningful, long-distance travel may matter less if access to human capital is indeed the main channel through which accessibilities affect innovation activities. Thus, we hypothesize:

Hypothesis 2: *Better accessibility by car and local public transport is more important for innovation activity than accessibility via long-distance travel.*

In the case of individual mobility by car, we further expect that accounting for congestion should provide a more accurate reflection of actual accessibility. That is, the measure for *congested car accessibility* should be stronger correlated to innovation as compared to a freeflow measure.

In addition, measuring regional innovation performance can be challenging as common indicators, such as patent-based measures, capture only particular forms of technological innovation. In line with prior research using patents as a measure of innovation activity, we expect inventors to locate in areas that are well accessible so that they can commute to work at companies for which they invent or become employed. Accessible locations may also have the advantage of supplying skilled engineers who develop the invention into a marketable innovation. Nevertheless, the advantage of locating in very accessible locations may (strongly) decline as such locations may be more costly to live in, and the benefits in terms of tapping into the regional knowledge pool may not increase proportionally with declining distance.

Following these arguments, we hypothesize that:

Hypothesis 3: *The more accessible a location is, the higher the number of patent applications in that region, but the positive correlation between accessibility and patent application numbers diminishes at very high accessibilities.*

The PIP captures product and service innovation, and for the successful introduction of new products, the location may matter not only because of access to human capital but also through market access. This implies that the benefits from being located in a better accessible region may be more pronounced than in the case of inventive activities. This is because of the increased importance of the business channel. Particularly for young and smaller firms with the need to attract new employees as well as customers, accessibility may be necessary. Moreover, older small and medium-sized firms may find recruiting qualified personnel challenging as they may have a comparative disadvantage vis-à-vis larger firms that possess highly professional human resource departments and the financial slack to hire specialized headhunters. Especially for firms in knowledge-intensive industries, it may be essential to be close to the relatively scarce qualified expert knowledge on science and engineering (Braguinsky et al., 2012).

Following these arguments, we hypothesize that:

Hypothesis 4: *The more accessible a location is, the higher the regional Product Innovator Probability, with this correlation being stronger for young and small than for established and larger firms.*

Table 2.1 summarizes the main expectations based on the discussed arguments.

Table 2.1: Overview of Expected Relationships

		Accessibility			
		Individual Level		Short Distance	Long Distance
		Car	Congested Car	Local BMT	Rail
Innovation Measure	Patents	+	++	++	+
	PIP	+	++	++	+
	PIP_{small}	+	+	+	+
	PIP_{large}	+	++	++	+
	PIP_{young}	+	+	+	+
	$\text{PIP}_{established}$	+	++	++	++
	$\text{PIP}_{manufacturing}$	+	++	+	+
	$\text{PIP}_{services}$	+	+	++	+

Note: BMT = Bus, Metro, Tram.

2.6 Data and Estimation

For the empirical analysis, we combine accessibility measures, innovation indicators, and regional characteristics at the accessibility zone level.

2.6.1 Descriptive Statistics

The variables describing the different accessibilities are normalized between zero and one to achieve comparability between modes.

As can be seen in Table 2.2, there are similarities and differences when comparing different modes of transport and different regions[5]. As expected, the accessibility is lower for the congested car mode compared to the freeflow car mode. When employing different values for the time-sensitivity parameter β, we see an adjustment in the average accessibility across modes. The higher β, the more long travel times are penalized, which results in lower values of accessibility.

Table 2.2: Descriptive Statistics of Accessibility Transport Modes

Accessibility	Mean	SD.	Min	.25	Mdn	.75	Max
Freeflow Car $\beta = 0.4$	0.69	0.15	0	0.59	0.70	0.81	1
Freeflow Car $\beta = 0.6$	0.56	0.16	0	0.45	0.56	0.69	1
Freeflow Car $\beta = 0.8$	0.47	0.16	0	0.36	0.46	0.58	1
Freeflow Car $\beta = 1.0$	0.40	0.15	0	0.30	0.38	0.50	1
Congested Car $\beta = 0.4$	0.61	0.15	0	0.51	0.61	0.72	1
Congested Car $\beta = 0.6$	0.48	0.15	0	0.37	0.48	0.59	1
Congested Car $\beta = 0.8$	0.40	0.15	0	0.30	0.39	0.50	1
Congested Car $\beta = 1.0$	0.35	0.14	0	0.26	0.34	0.44	1
Local BMT $\beta = 0.4$	0.23	0.14	0	0.14	0.20	0.29	1
Local BMT $\beta = 0.6$	0.16	0.12	0	0.08	0.13	0.19	1
Local BMT $\beta = 0.8$	0.11	0.11	0	0.05	0.08	0.13	1
Local BMT $\beta = 1.0$	0.08	0.09	0	0.03	0.05	0.09	1
Long-distance Rail $\beta = 0.4$	0.39	0.18	0	0.27	0.39	0.51	1
Long-distance Rail $\beta = 0.6$	0.27	0.16	0	0.15	0.26	0.37	1
Long-distance Rail $\beta = 0.8$	0.19	0.14	0	0.09	0.17	0.27	1
Long-distance Rail $\beta = 1.0$	0.14	0.12	0	0.05	0.11	0.19	1

Note: n = 11717; $\alpha = 1.0$; BMT = Bus, Metro, Tram.

Different modes have a differing number of zones that are included in the calculation resulting in a varying n, according to the availability of the respective transport mode. Turning to the innovation measures, we find similarities as well as differences when comparing

[5] Accessibilities by different transport modes are correlated, but not perfectly. The pair-wise correlation coefficient between congested car and freeflow car is 0.89 (for $\beta = 2.5$), the one between congested car and BMT is 0.24, the coefficient for BMT and LDR is 0.81, and the one for congested car and LDR is 0.29.

the PIP to patent applications. The zone-level PIP is expressed as a value from zero to 8000 based on the PIP of firms in the same zone. At the same time, the patent numbers are the accumulated number of patent applications in a zone during our observation period. From that and the information on the total number of firms in a zone, we can calculate the Innovator Share, which is the share of product innovators in a region relative to all firms (with a website) in that area. From the MUP database, the incorporation date of each firm allows us to calculate the age of each firm and hence the number of young firms (firm age $\leq$ ten years) per zone. From that number, we can derive the share of young innovative firms in all firms (Young Innovator Share). Based on the number of employees recorded in the MUP data, we can additionally obtain a proxy for firm size and distinguish small from larger firms. Moreover, we can use the industry affiliation of firms to differentiate between service and manufacturing companies. Note that we do not have PIP values for zones without any firms with a website.

Figure 2.6 shows the distribution of the PIP as the total sum in Figure (a) and normalized by the population in the respective zones in Figure (b)[6]. We see two major differences when we compare this to the respective maps based on patents in (c) and (d). The first is that when looking at patents, larger cities are indeed less pronounced in terms of patent applications per capita compared to smaller cities and more rural areas. This insight aligns with findings by (Fritsch and Wyrwich, 2021a, 2021b).

When looking at patents, the location of headquarters of certain companies is quite visible such as in car manufacturing (headquarters of Volkswagen AG in the center north of Germany and car manufacturers in the southwest, i.e., Daimler AG, and southeast, i.e., BMW) and locations that are less manufacturing intensive such as Berlin. The PIP, on the other hand, shows higher innovation intensities in urban areas as well as in some areas like the Saarland, where there is considerably less patenting. This indicates that the PIP also captures non-technological product and service that is not visible in patent indicators. The pair-wise correlation between the PIP and the number of patent applications in a zone across all zones is 0.11 and 0.16 with the logged number of patent applicants.

[6]Information about the population density within was retrieved from the federal statistical office: https://destatis.com. Last accessed on 31.05.2023. We then assigned these values to the corresponding zones. Some unincorporated areas, like forests or lakes, have a population of 0.

Table 2.3: Descriptive Statistics: Innovation Indicators

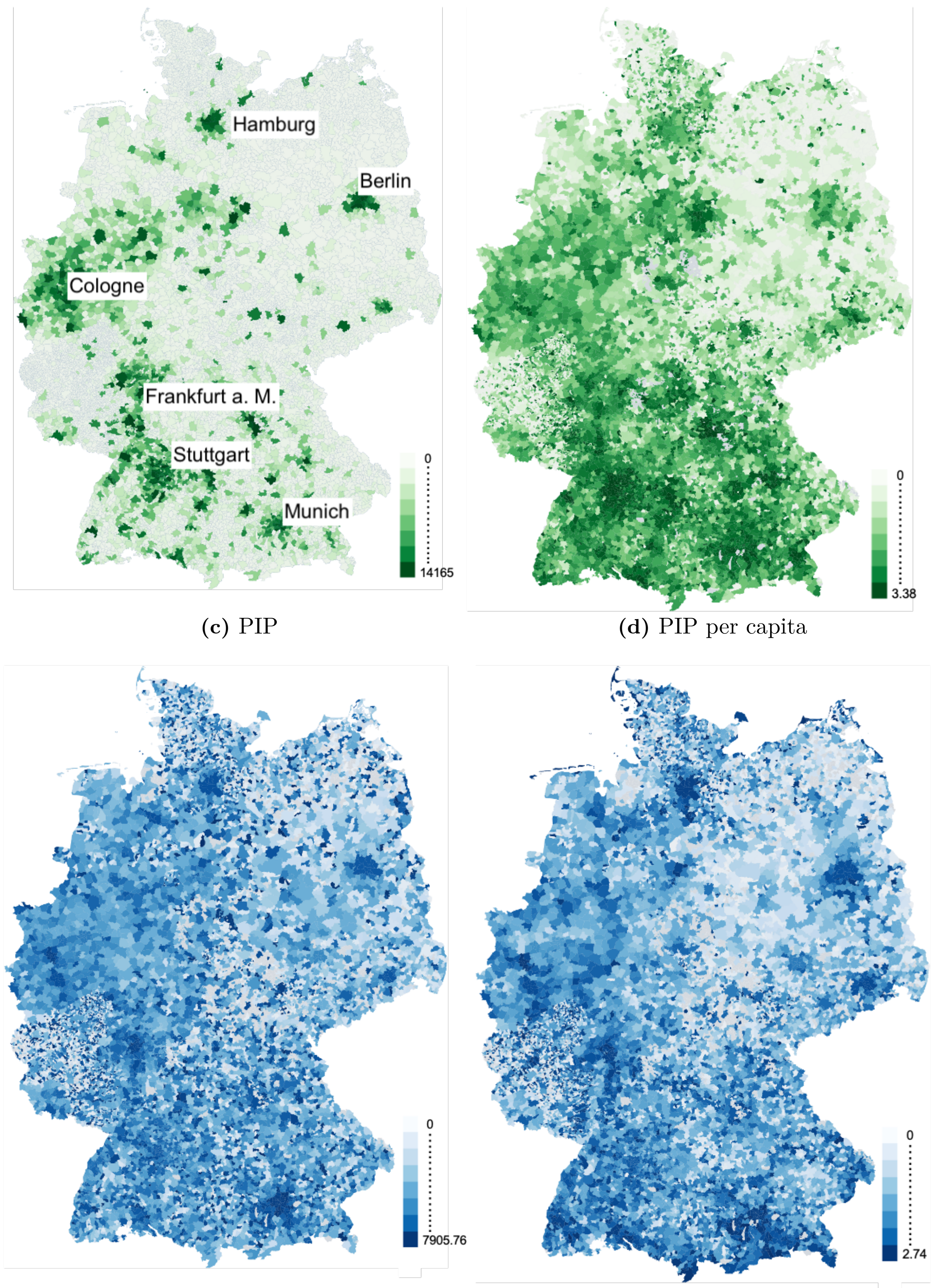
Variable	n	Mean	S.D.	Min	Median	Max
PIP	10071	46.90	384.80	0.05	2.69	7905.76
Number of Firms:						
Firm Total	10071	163.05	1292.01	1	11	27469
Manufacturing Firms	10071	22.44	140.48	0	4	3120
Service Firms	10071	139.70	1144.54	0	7	24128
Small Firms	10071	22.86	182.13	0	1	4015
Large Firms	10071	11.46	87.03	0	1	1854
Young Firms	10071	45.69	394.82	0	2	8810
Established Firms	10071	104.54	786.32	0	8	16259
Number of Innovative Firms:						
Firms	10071	32.18	284.78	0	1	5615
Manufacturing Firms	10071	2.98	20.56	0	0	414
Service Firms	10071	29.06	263.05	0	1	5158
Small Firms	10071	4.82	42.57	0	0	842
Large Firms	10071	3.10	26.57	0	0	515
Young Firms	10071	12.35	120.84	0	0	2632
Established Firms	10071	17.94	147.17	0	1	2616
Innovator Share (in %)	10071	11.41	14.79	0	9.09	100
Young Innovator Share (in %)	10071	3.19	7.93	0	0	100
Patent Applications	11717	127.56	522.55	0	10	14165
Patent Applications Log	11717	2.56	2.13	0	2.40	9.56

Note: Firms with websites; Young firms: firms that are 10 years or younger; Manufacturing firms: active in NACE Rev.2 $<$ 45.000. Small firms: 10 employees or less. Patent applications are counted between the years 2000-2014.

Figure 2.6: Distribution of PIP and Patent Applications in Germany

(a) Patent applications **(b)** Patent applications per capita

(c) PIP **(d)** PIP per capita



Distribution of PIP (a, b) and Patent Applications in Germany between 2000 and 2014 (c) and both Variables per Capita (b and d).

2.6.2 Estimation Method

To understand how accessibilities are linked to innovation performance, we model regional innovation indicators as a function of accessibilities as well as the characteristics of the zone. More precisely, we estimate ordinary least squared (OLS) regression models to investigate the relationship between the accessibility of a municipality and its impact on the local innovation activity, represented by the number of patent applications, as well as the PIP value.

We control for each zone's (logged) area size and a border region indicator to capture peculiarities of such zones, the (logged) number of manufacturing and service firms as well as shares of young and small firms.

We assume that a location's accessibility is constant in the short to medium term and is not driven by innovation in the short term. In the following analysis, we explore a cross-sectional variation of innovation activities between locations with different accessibilities , estimating a linear regression model. Thus, we model innovation performance y for German regions i such that:

$$y_i = \gamma + \delta Accessibility_i + \epsilon Accessibility_i^2 + \zeta x_i + \nu_i \tag{2.6.1}$$

with x_i capturing the control variables. We test potentially diminishing returns to better accessibility and include the second-order term of the $Accessibility_i$. The outcome variable y captures the log of the number of patents in a zone or the PIP measures. We employ the different accessibilities (congested and freeflow car, local public transport, and long-distance rail travel) as outlined above in separate models. Note that we cannot investigate the causal effects of transport infrastructure on innovation using this econometric approach as both the PIP and the accessibility are time-invariant. However, studying correlations can be informative of the general patterns that can be observed across zones.

2.7 Results

Tables 2.4 and 2.5 show the results for patents (log of count) and the PIP indicator as dependent variables. For each set of models, we employed four different modes of transport (freeflow car, congested car, local BMT, and long-distance rail). In line with Hypothesis 1, we see that a zone's better accessibility is associated with higher patent application numbers (see Table 2.4) as well as with a higher PIP in the zone (see Table 2.5). This is reflected in statistically significant positive coefficients ($p < 0.001$) for the patent applications and PIP and all transport modes. In addition, the squared accessibility is negative and significant for all four accessibilities indicating an inverse U-shaped relationship between accessibility and patenting. We observe a similar pattern for the PIP, except for local BMT where the second-order term has a negative sign but is statistically insignificant.

In more detail, the results indicate that good freeflow car accessibility is connected to significantly more local patenting activity (8.856) and a higher local PIP (β=10.006). The more realistic scenario of congested car accessibility also leads to a higher number of patent applications (β=9.078) and a higher PIP (β=10.293). Local public transport also seems to increase patent applications (β=7.133) and PIP (β=4.359). Accordingly, the long-distance rail service makes a significant difference for the patent applications (β=6.713) and PIP (β=5.839) in a region. The second hypothesis that better accessibility by car and local public transport is more important for innovation activity than accessibility via long-distance travel is not confirmed by the data. For patent applications, the local public transport obtains a slightly higher coefficient than long-distance rail travel, and for the PIP it is even slightly lower. Overall the R^2 is higher for the patent application regressions (between 0.670 and 0.684) than for the PIP (between 0.149 and 0.154). Without any control variables, we obtain R^2 of 0.28 for LD Rail in the patent estimation and 0.03 in the PIP model, for instance. This dynamic indicated that regional characteristics alone explain quite some variation in the outcomes.

To better understand the results, Figure 2.7 illustrates the results graphically. It shows that the better the accessibility, the higher the number of patent applications and the PIP. The effect is also economically meaningful as the number of patent applications doubles when we compare zones with a 0.2 accessibility with zones with a 0.4 accessibility. This suggests that the most accessible zones actually show lower patent application numbers compared to average accessible places. However, this relationship slightly reverses at very high accessibilities. This downward slope is, however, more pronounced in the case of patents, particularly for congested car and local BMT. It should be noted that the downward slope represents observations beyond the 95th percentile so that for the vast majority of zones, we can conclude that better accessibility is associated with more innovation - both in terms of patents as well as the PIP. Interestingly, this is true for all modes of transport.

For the control variables, we find that some of the variables impact both the number of patent applications and the PIP, but there can also be seen some differences. Regarding other zone characteristics, we find that manufacturing intensity predicts patents positively but the PIP negatively. This confirms that the PIP captured product and service innovation not necessarily based on patentable technology. Area size correlates positively with patents but negatively with PIP. This illustrates that the PIP is higher in cities where zones tend to be smaller, while patenting intensities are higher in larger zones that are typically found outside of major cities. Interestingly, the share of young firms (younger than ten years) predict both patenting and the PIP, confirming earlier research that showed that start-ups are key drivers of regional innovation. Patenting activity and the PIP also seem to be impacted by large and small companies similarly; there is only a slightly higher effect coming from large firms. Border regions do not seem to differ with regard to the innovation measures, except for a slightly negative impact on local public transport on patent applications.

2.7.1 Interdependencies between Traffic Modes

The question remains whether, for example, good local public transport accessibility also seems to increase innovation activity even if the car accessibility in that region is lower. Thus, we evaluated interdependencies between the transport modes, which are discussed in the next section. To check whether the traffic modes inter-depend on each other, we include the interaction terms between car accessibility and local and long-distance public transportation. Table 2.6 shows the results. While the individual terms are still positive and significant, the interaction term is negative, indicating that car accessibility and public are substitutes, at least at lower ranges of car accessibility. As can be seen in Figure 2.8, the different public transport accessibilities do not serve as an enhancer in terms of the PIP and patents when there is already good accessibility via car accessibility. Thus, public transport substitutes for car accessibility to a certain extent (and vice versa). Since including congestion is more calculation, we present the inter-dependencies for freeflow car accessibility only in the Appendix (Figure A.1.2).

2.7.2 Firm Type Heterogeneity

Additionally, we are interested in testing whether accessibility has a varying effect when we take into account firms with different characteristics. Using the PIP, we can differentiate between the scores for young ($\leq$ 10 years) versus established firms, small ($\leq$ 10 employees) versus large firms as well as manufacturing versus service firms. We find that accessibility matters for both young and established firms. It should be noted that the groups of young and small firms overlap, as well as established and large firms but that car and long-distance

Table 2.4: Regression Results for Patent Applications

Patent Applications Accessibility: $\beta = 1.0$	Car Freeflow	Car Cong.	Local BMT	LD Rail
Freeflow Car	8.856***			
	(0.309)			
Freeflow Car^2	-7.873***			
	(0.341)			
Cong. Car		9.078***		
		(0.329)		
Cong. Car^2		-8.246***		
		(0.361)		
Local BMT			7.133***	
			(0.430)	
Local BMT^2			-13.567***	
			(0.953)	
LD Rail				6.713***
				(0.264)
LD Rail^2				-8.913***
				(0.468)
Population	0.569***	0.573***	0.590***	0.538***
	(0.042)	(0.042)	(0.045)	(0.041)
Manu. Firms (ln)	0.173***	0.179***	0.244***	0.222***
	(0.026)	(0.026)	(0.027)	(0.026)
Service Firms (ln)	0.324***	0.325***	0.293***	0.283***
	(0.030)	(0.030)	(0.031)	(0.029)
Small Firms (%)	0.284**	0.278**	0.120	0.212*
	(0.102)	(0.103)	(0.104)	(0.104)
Young Firms (%)	0.004***	0.005***	0.005***	0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
Area Size (ln)	-0.001	-0.010	-0.072**	-0.024
	(0.023)	(0.023)	(0.024)	(0.024)
Border Region	-0.028	-0.026	-0.098	-0.019
	(0.052)	(0.052)	(0.055)	(0.055)
Constant	-4.773***	-4.808***	-3.039***	-3.009***
	(0.210)	(0.213)	(0.223)	(0.199)
R-squared	0.684	0.683	0.670	0.677
Observations	10042	10042	10042	10042

Notes: Ordinary Least Squares (OLS) are used to estimate all models. Each observation corresponds to a given zone with an accessibility and a PIP value. The standard error is clustered at the zone level. Significance noted as: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2.5: Regression Results for PIP

PIP Accessibility: $\beta = 1.0$	Car	Car Cong.	Local BMT	LD Rail
Freeflow Car	10.006***			
	(1.377)			
Freeflow Car^2	-7.536***			
	(1.300)			
Cong. Car		10.293***		
		(1.395)		
Cong. Car^2		-7.973***		
		(1.307)		
Local BMT			4.359**	
			(1.376)	
Local BMT^2			-2.341	
			(1.845)	
LD Rail				5.839***
				(1.187)
LD Rail^2				-4.657**
				(1.598)
Population	-0.215	-0.207	-0.159	-0.237
	(0.169)	(0.169)	(0.169)	(0.170)
Manu. Firms (ln)	-0.908***	-0.898***	-0.858***	-0.846***
	(0.127)	(0.127)	(0.128)	(0.127)
Service Firms (ln)	1.239***	1.240***	1.149***	1.171***
	(0.140)	(0.140)	(0.141)	(0.140)
Small Firms (%)	-0.471	-0.476	-0.668	-0.593
	(0.701)	(0.701)	(0.702)	(0.702)
Young Firms (%)	0.106***	0.106***	0.107***	0.107***
	(0.004)	(0.004)	(0.004)	(0.004)
Area Size (ln)	-0.478***	-0.496***	-0.558***	-0.518***
	(0.079)	(0.078)	(0.092)	(0.091)
Border Region	0.006	-0.007	-0.087	0.004
	(0.212)	(0.212)	(0.214)	(0.213)
Constant	22.036***	21.992***	24.287***	24.328***
	(0.939)	(0.943)	(0.913)	(0.914)
R-squared	0.154	0.154	0.149	0.151
Observations	10042	10042	10042	10042

Notes: Ordinary Least Squares (OLS) are used to estimate all models. Each observation corresponds to a given zone with an accessibility and a PIP value. The standard error is clustered at the zone level. Significance noted as: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 2.6: Interdependencies between Modes of Transport with Congested Car Accessibility

	(1) Patent Applications Local BMT	(2) Patent Applications LD Rail	(3) PIP Local BMT	(4) PIP LD Rail
Cong. Car	2.488***	1.951***	5.020***	5.017***
	(0.155)	(0.144)	(0.853)	(0.763)
Local BMT	10.279***			10.548**
	(0.995)			(3.590)
Local BMT^2	-14.709***			-1.646
	(2.137)			(5.448)
Local BMT × Cong. Car	-8.824***			-21.325***
	(1.842)			(6.332)
Local BMT^2 × Cong. Car	7.176*			14.991
	(3.245)			(9.062)
Manu. Firms (ln)	0.382***	0.355***	-1.012***	-1.019***
	(0.024)	(0.024)	(0.118)	(0.119)
Service Firms (ln)	0.610***	0.575***	1.026***	1.021***
	(0.019)	(0.019)	(0.096)	(0.097)
Small Firms (%)	0.257*	0.325**	-0.446	-0.468
	(0.107)	(0.106)	(0.700)	(0.701)
Young Firms (%)	0.005***	0.005***	0.106***	0.106***
	(0.001)	(0.001)	(0.004)	(0.004)
Area Size (ln)	0.194***	0.205***	-0.431***	-0.400***
	(0.020)	(0.019)	(0.080)	(0.082)
Border Region	-0.065	0.005	0.089	0.011
	(0.056)	(0.056)	(0.213)	(0.213)
LD Rail		7.059***	10.528***	
		(0.680)	(2.993)	
LD Rail^2		-5.434**	-1.518	
		(2.018)	(5.367)	
LD Rail × Cong. Car		-3.042**	-19.908***	
		(1.169)	(5.442)	
LD Rail^2 × Cong. Car		-2.100	10.836	
		(2.350)	(7.312)	
Constant	-1.198***	-1.140***	21.162***	21.292***
	(0.088)	(0.079)	(0.420)	(0.426)
R-squared	0.660	0.666	0.155	0.154
Observations	10042	10042	10042	10042

Notes: Ordinary Least Squares (OLS) are used to estimate all models. Each observation corresponds to a given zone with an accessibility and a PIP value. The standard error is clustered at the zone level. Significance noted as: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

rail seems to matter most.

Contrary to our expectations for established firms, good car, and long-distance rail accessibility seems to be of significantly more value than for young firms. This is different for small and large firms, where car accessibility is significantly and positively related to large firms' innovation rather than small firm's ones. This might be because large firms often have larger offices or factories and need more space in rural areas, which are predominantly accessible by car. Innovating manufacturing firms are more affected by better car and long-distance rail accessibility. Service companies' innovation is much less explained by accessibility.

See Table 2.7 for the results from the firm-type comparison.

2.8 Discussion and Conclusion

Previous research on regional economic performance stressed the importance of local characteristics for invention and innovation. This study contributes to research on differences in regional innovation activities by investigating the role of location-based accessibility. We measure accessibility using a fine-grained zone system in Germany which allows us to capture different modes of transport as well as congestion on roads. The resulting accessibility scores capture a location's potential access to human capital since we use population as the main attractor. We distinguish between public transport (bus, metro, tram, long-distance rail) and accessibility by car. Our descriptive analysis shows that locations differ quite substantially in terms of accessibility and that accessibility captures more than a simply urban/rural dichotomy. Our measures, therefore, qualify earlier work that challenged the assumption that innovation predominantly happens in big cities (Fritsch and Wyrwich, 2021a).

Our results based on about 11,700 zones within Germany show that better accessibility is associated with higher innovation performance. This relationship holds for public transport as well as car travel. Moreover, it holds different measures of innovation. Recent empirical analyses that use patent data as the primary measure for inventive activity find that inventions happen not only in larger cities (Berkes and Gaetani, 2021) but also in peripheral areas (Fritsch and Wyrwich, 2021a, 2021b). Our results based on patent data suggest that this may be related to local accessibility, which can be rather good also in non-urban areas. In addition to using patent applications as outcomes of inventive efforts, we make use of a novel innovation indicator that captures also non-technical and non-patentable innovation activity. The Predicted Innovator Probability (PIP) is retrieved using firms' website infor-

Table 2.7: Firm Type Comparison

	Young Firms	Established Firms	Prob > χ^2
Cong. Car	0.082*** (0.021)	0.193*** (0.042)	0.007
Cong. Car^2	-0.065** (0.022)	-0.167*** (0.045)	0.008
R^2	0.0207	0.0194	
Local BMT	0.038 (0.021)	0.061 (0.041)	0.543
Local BMT^2	0.015 (0.037)	-0.052 (0.073)	0.195
R^2	0.0197	0.0168	
LD Rail	0.048** (0.016)	0.120*** (0.031)	0.029
LD Rail^2	-0.033 (0.028)	-0.138* (0.056)	0.018
R^2	0.0199	0.0183	
Observations	10042	9637	
Controls	yes	yes	
	Small Firms	Large Firms	Prob > χ^2
Cong. Car	0.179** (0.064)	0.487*** (0.093)	0.001
Cong. Car^2	-0.127 (0.066)	-0.415*** (0.092)	0.001
R^2	0.1083	0.0421	
Local BMT	0.006 (0.060)	0.078 (0.080)	0.417
Local BMT^2	0.070 (0.103)	-0.087 (0.132)	0.167
R^2	0.1066	0.0365	
LD Rail	0.092 (0.048)	0.264*** (0.066)	0.021
LD Rail^2	-0.070 (0.080)	-0.359*** (0.106)	0.002
R^2	0.1072	0.0392	
Controls	yes	yes	
Observations	6844	5420	
	Manufacturing Firms	Service Firms	Prob > χ^2
Cong. Car	0.183*** (0.046)	0.108* (0.042)	0.205
Cong. Car^2	-0.126** (0.049)	-0.078 (0.045)	0.383
R^2	0.0500	0.1765	
Local BMT	0.074 (0.042)	0.040 (0.039)	0.485
Local BMT^2	-0.036 (0.078)	0.044 (0.074)	0.250
R^2	0.0467	0.1764	
LD Rail	0.141*** (0.034)	0.037 (0.032)	0.021
LD Rail^2	-0.140* (0.059)	0.013 (0.056)	0.012
R^2	0.0489	0.1763	
Controls	yes	yes	
Observations	8603	9492	

Notes: Ordinary Least Squares (OLS) are used to estimate all models. Standard deviation in brackets. Significance noted as: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

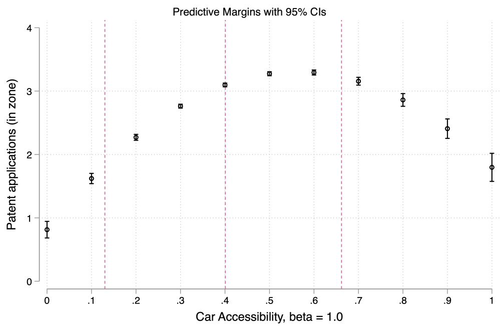
mation and training data from the Community Innovation Survey (CIS). Interestingly, the results using the PIP are qualitatively similar to those for patents. However, we find that innovation in highly accessible places may be better captured by the PIP, which includes services, for instance. Unlike for patents, where we observe a saturation point beyond the media accessibility, we do not find such saturation for the PIP. This could be due to the fact that we allocate patents to inventor addresses, and inventors may prefer to live in the suburbs. This may lead to an underestimation of the link between accessibility and innovation in highly accessible places (for instance, next to the central train station or interchanges) where inventors may not reside.

Accessibility seems to have varying impacts on firms with contrasting characteristics, but the differences are minor and require further investigation. The question remains whether accessibility is higher in bigger cities due to a higher availability of transport modes since the different modes of transport also seem to be substitutes for each other. Understanding this in more detail could further strengthen the role of (smaller) cities with good accessibility for a specific mode of transport.

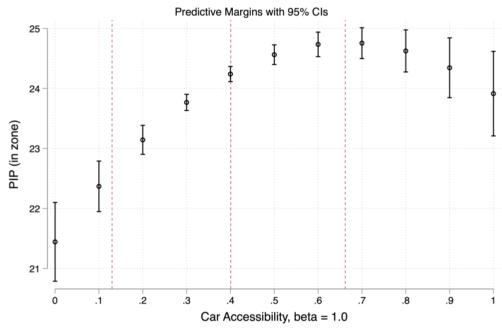
Providing new insights on the link between transport infrastructure and innovation, the results of this study emphasize that even in the digital age, the accessibility of locations seems to have an impact on innovation activity. The study has several limitations. First, since Germany is an economically decentralized country, it would be interesting to compare this structure to other countries which are set up as more centralized, like France, or polarized, like the United States. Second, in developed economies like Germany, transport infrastructure, as well as mobility patterns and population size, are relatively constant in the short to medium term. Studying the role of accessibility in less developed economies for innovation would therefore be extremely interesting. Finally, path dependencies and the lack of lasting infrastructure shock prevent the identification of causal effects in our setting. The construction of a more extended time series of accessibility information may be a starting point for such analyses in the future.

Figure 2.7: Regression Result Graphs for Patent Applications and PIP

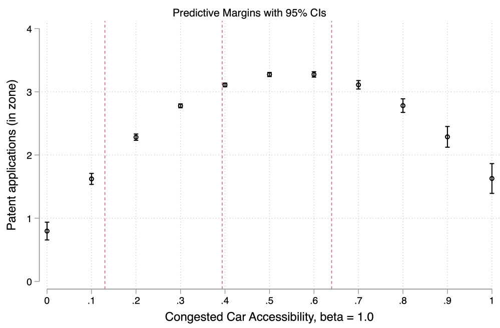
(a) Patent Applications: Freeflow Car



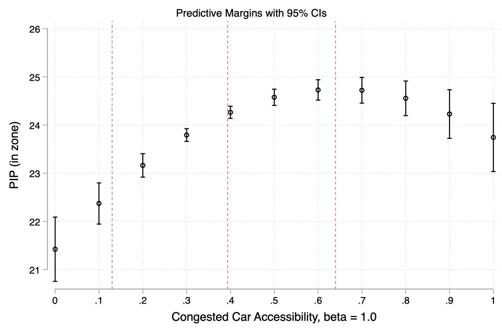
(b) PIP: Freeflow Car



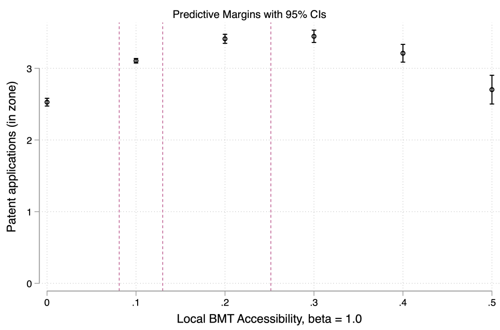
(c) Patent Applications: Congested Car



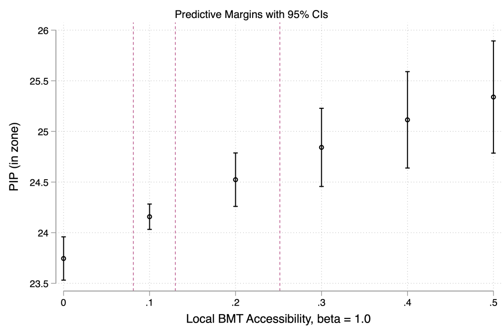
(d) PIP: Congested Car



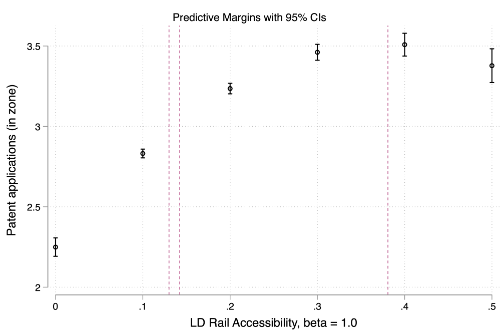
(e) Patent Applications: Local Bus, Metro, Tram



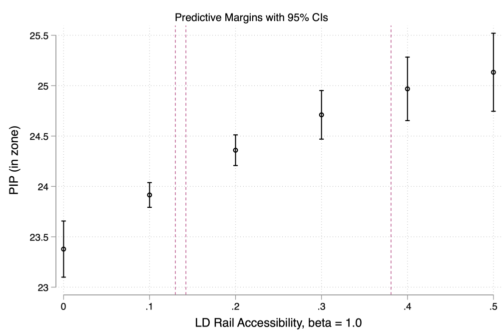
(f) PIP: Local Local Bus, Metro, Tram



(g) Patent Applications: LD Rail



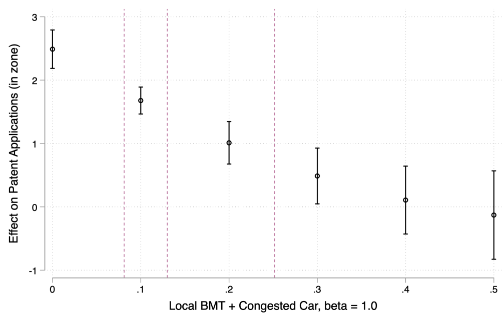
(h) PIP: LD Rail



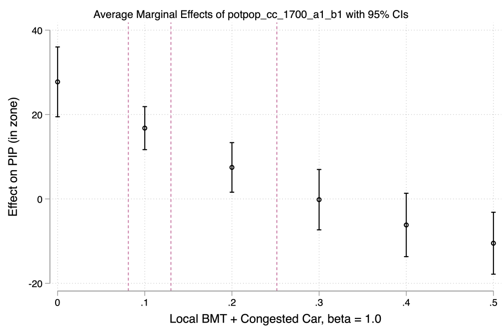
Accessibility weights at $\alpha = 1.0$, $\beta = 1.0$. Average marginal effects of variable with 95% CIs. Dotted lines mark the accessibility mean, median, and 95th percentile.

Figure 2.8: Result Graphs for Interdependencies between Modes of Transport with Congested Car Accessibility

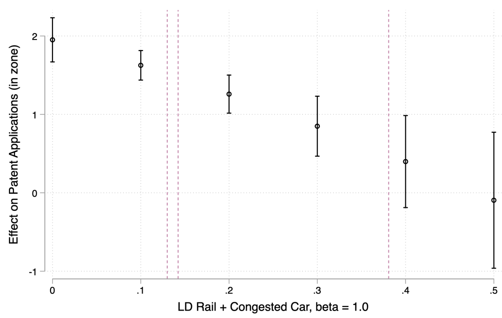
(a) Patent Appls: Local BMT + Congested Car



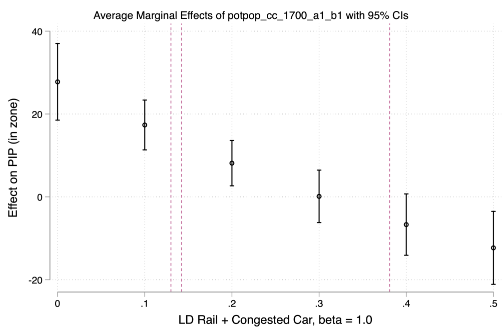
(b) PIP: Local BMT + Congested Car



(c) Patent Appls: LD Rail + Congested Car



(d) PIP: LD Rail + Congested Car



Accessibility weights at $\alpha = 1.0$, $\beta = 1.0$. Average marginal effects of variable with 95% CIs. Dotted lines mark the accessibility mean, median, and 95th percentile.

3 | Where Do I Even Start? Location Choice of Entrepreneurs and the Role of Transport Accessibility

3.1 Abstract

Although the impact of local characteristics on startup founding activities has been extensively researched, the extent to which accessibility influences the location choices of young firms remains largely unexplored. This study utilizes data from a nationwide agent-based transport model in Germany to calculate travel times and accessibility for various modes of transportation while accounting for road congestion. These accessibility measures are then used to examine their significance in entrepreneurs' decisions when selecting a location to establish a firm. In the second part of the study, the underlying reasons for a founder's location choices are investigated by analyzing qualitative interview data from German startups regarding their business location choice. The quantitative findings indicate increased startup founding activity in regions with better accessibility, which is further supported by the qualitative data. Accessibility appears to be a crucial factor for founders due to the availability of skilled human capital and the minimization of transportation costs in more accessible regions. These findings have implications for research on transport accessibility, where entrepreneurs establish companies and their methods.

3.2 Introduction

Newly founded firms are increasingly in the focus of economic research because of their crucial role in enhancing innovation and technological progress through contributing to the development of radically new products (Acs and Audretsch, 1988; Haltiwanger et al., 2013; Schneider and Veugelers, 2010; Pellegrino et al., 2012). Furthermore, employment creation is disproportionately driven by startups (Haltiwanger et al., 2016; Stuetzer et al., 2018). Young firms also enhance the competitive pressure on incumbents in their respective technology fields (Changoluisa and Fritsch, 2020) and directly and indirectly contribute to a region's economic development (Audretsch and Keilbach, 2004). However, startups have to overcome financial constraints to develop and grow their business and, therefore, make wise decisions when first starting out. Besides developing the business idea itself, founders have to be able to hire skilled workers, work from an office, access materials for their product or service, and distribute their invention among customers. This dynamic requires a careful decision on *where* to start up a new firm.

As Chapter 2 already prevailed and research has also shown, local characteristics seem essential for regional economic and innovation advances (Feldman, 1999; Czarnitzki and Hottenrott, 2009). Locational factors are, therefore, important focus points not only for established but especially for young companies. Regional conditions, like the size of local business taxes, the availability of land or office space, and accessibility for potential employees, can impact a firm's location choice. There already exists extensive literature on how established companies choose a new location when branching out or relocating, as researchers found agglomeration effects (Stuart and Sorenson, 2003), access to suppliers (Pe'er and Keil, 2013), skilled labor (Egeln et al., 2004), customers (Stearns et al., 1995), the availability of financiers (Kolympiris et al., 2015), knowledge spillovers (Delerue and Lejeune, 2012), and accessibility and proximity to good transport infrastructure (De Bok and Sanders, 2005) as influencing firms' location choices. Therefore, the impact of location on young companies in this context deserves further investigation.

As already mentioned, young companies can have a significant impact on local economic ecosystems. However, young innovative firms that are just starting out have different requirements than established firms due to their generally high research and development (R&D) efforts (Hottenrott and Richstein, 2020). Results of Pe'er and Keil (2013) and Minai (2011) suggest that location factors, such as the regional availability of knowledge workers, knowledge transfer from other businesses, suppliers, subsidy givers, and customers, influence the growth and survival rate of new companies. Thus, startups can benefit highly from connections to other firms, universities, innovation hubs, entrepreneurship centers, and an extensive and skilled employee pool (Mazzarol and Choo, 2003). Previous research found that entrepreneurs prefer to locate their business in areas where they can use their existing network and connections; this is, for example, close to a prior employer (Feldman et al., 2004; Stuart and Sorenson, 2003). Moreover, Woo and Kim (2021) indicate that especially regional human capital is critical when choosing a location for small businesses. Existing literature additionally implies that most startups seem to cluster close to other companies within their industry sector in order to benefit from knowledge exchanges (Feldman et al., 2004; Audretsch and Keilbach, 2007). This dynamic seems to indicate that startup firms prefer moving to places with more opportunities for their business. However, Hellwig (2023) found that young companies tend to stay where they are and not move or relocate - even if that means less beneficial location factors.

De Bok and Van Oort (2011) discovered that accessibility plays a role in the location decisions of startups. However, due to the diverse strategic orientations of firms, unique sets of locational factors are required, depending on, for example, whether the firm produces a physical product or provides a (software) service. This could affect the necessity for certain accessibility if some companies require access to highways and railway stations while others offer their services entirely online. Still, the main reasons for a specific choice of location for young companies seem to be: the employment and commute of skilled workers, the procurement of materials and inputs, and the distribution of products or services to customers (Acs et al., 2007). These factors are, however, directly or indirectly dependent on the transport accessibility of a business site. Nevertheless, little is known about why startups choose their locations and whether transport accessibility plays a role in their decision, and insights into this relationship still seem ambiguous. Prior research also focused on comparing cities and rural areas with one another in terms of location factors. This essay tries to go beyond this dichotomy and focus on the accessibility of all types of locations. This could reveal further insights into what happens in small to medium-sized urban locations and rural areas. This is especially interesting in Germany, which is historically structured in a decentralized manner; thus, studies find a lot of innovation behavior is happening outside of large cities (Fritsch and Wyrwich, 2021a, 2021b).

Therefore, I investigate whether the transport accessibility of a location is a factor that entrepreneurs include in their early business decisions. Following on the existing literature, it could be that due to the prospect of more skilled and knowledgeable workers at specific locations, more founders locate in highly accessible areas. However, founders could also prefer rural areas, where land and space are less expensive and business taxes are low. Therefore, I utilize qualitative and quantitative analysis of the proposed research questions to gain insights into the proposed dynamic. The quantitative part examines whether the accessibility of a location has an impact on local startup founding rates. For this, I make use of the same accessibility measurement as in 2. This describes the transport accessibility data at roughly the municipality level in Germany. The concluding agent-based model considers travel times, travel distances, the road and rail network, and a German-wide zone system to calculate free-flow as well as congested traffic travel accessibilities for each of the 11,717 pre-defined zones. In this chapter, I also distinguish who or which group of people is traveling. Therefore, I utilize the accessibility to the general population, potential employees, and potential research employees, and the mode of transport (car, trains, public transport). Data on how many startups are founded in a zone stems from the Mannheim Enterprise Panel (MUP), a database for established and new companies in Germany (Bersch et al., 2014).

The regression analysis results indicate that areas with better accessibility also have a higher number of startups. However, this numerical relationship does not reveal whether accessibility was the primary driver for founders' location decisions or rather a necessity. To further investigate this, a qualitative interview study examines entrepreneurs' complex decisions when establishing their businesses. Therefore, founders of eleven startups throughout Germany were interviewed in a semi-structured manner about their firms' location choices. The qualitative portion of this study suggests that although most startups do not use traditional location assessment methods, there are factors that influence their decision on where to establish their business. Accessibility appears to be crucial for young firms in their early years due to the availability of more qualified personnel, customers, and resource material supplies. This is achieved by locating in highly accessible areas, and thus, the findings emphasize the importance of choosing a specific location for startups, even in today's digital age. This is also relevant to policymakers who examine and plan transport infrastructure and its relationship with local business activity.

This essay is structured as follows: First, I will review the current literature, identify potential research gaps, and formulate my research questions. In the subsequent chapter, I will describe the data sets, interview participants, and methods employed for quantitative and qualitative analyses. Finally, the results of both analyses will be discussed.

3.3 Theory and Hypotheses

Location factors and their impact on (new) firm performance have been extensively researched, and evidently, companies indeed seem to choose their business location wisely

(Pe'er et al., 2008). However, previous research has shown that the location choice of firms is a complex undertaking, given that the business itself and the environment of each business evolves over time and the contextual circumstances are ever-changing, and location factors are plentiful (Balbontin and Hensher, 2019). Nevertheless, the selection of location plays a critical role in the success of a company, as it depends on the most advantageous environmental factors and competition thereof (Audretsch and Dohse, 2004).

Consequently, the location selection needs to be thoughtfully considered, as it is not easily reversible. In the last decades, economic researchers found several spatial circumstances that influence firm entry, growth, and survival: Two primary considerations in this dynamic are, on the one side, specific firm characteristics and, on the other side, location characteristics of their current or possibly alternative site (Balbontin and Hensher, 2019). Different firm characteristics lead to a wide-ranging need for specific locations. These factors include the firm size, which, for example, determines the office size; the industry sector, which might be demanding large or small productions sites; or if the firm is, for instance, producing a regional product or service that is locally bound (e.g., a food product that the region is historically known for).

For the location characteristics, Feldman (1999) and Harhoff (1999) found agglomeration effects through knowledge spillovers from other firms as an influencing factor for the choice of location. In their study, Audretsch et al. (2012b) stated that infrastructure is a critical factor in site selection for firms. Others found that access to resource materials impacts the location choice of entrepreneurs (Polonyová et al., 2015). Czarnitzki and Hottenrott (2009) and Hoogstra and Van Dijk (2004) additionally stressed the value of a qualified workforce. Egeln et al. (2004) found that customer proximity and a qualified workforce are of greater importance than knowledge spillover from universities when it comes to the selection of a location. In addition, regulatory, political aspects and transportation costs are essential factors according to Delerue and Lejeune (2012).

With founders in mind, Salvesen and Renski (2003) referred to aspects such as quality of life and employee benefits being essential in recruiting and retaining workers. Home and family, as well as social ties, have been documented in literature as factors that contribute to the decision of a location for a startup (Dahl and Sorenson, 2012; Colombo et al., 2021). Although the spatial circumstances might not directly correlate to a startup's financing, investors, business angels, venture capitalists, crowd landing, and prototyping grants are commonly distributed in particular locations (Hottenrott and Richstein, 2020). Furthermore, Polonyová et al. (2015) highlights other local startups and universities as beneficial for entering firms. They investigated the location choices of UK academic founders. By analyzing the movement behavior of graduate entrepreneurs, they found that it is essential to have both supportive personal connections and face-to-face interactions when pursuing new business ideas. According to their insights, it is necessary to have an environment that is conducive to startups, which various cultural characteristics can represent. Knowledge spillovers through workers and university connections seem to impact discerning entrepreneurial possibilities most. Accordingly, developing knowledge through innovation is associated with the academic, research, and development environment. The labor market and the concentration of financial security and job opportunities are added aspects of a new business's location in their outcomes. They finally conclude that a city can provide an extremely attractive setting for new entrepreneurs. This is also indicated in the study of Larsson et al. (2017) where they find that academic founders also tend to locate in metropolitan areas, especially when they were born there or went to university locally. Renski (2008) also describes population-density differences in regions and their influence on firm site selection. They wanted to uncover whether entrepreneurial performance differs in urban, suburban, and rural locations. They surveyed startups from urban, rural, and suburban regions and found that in cities, young American companies tend to have higher failure rates, yet their employment growth in advanced services is more efficient. Rural locations lack high-tech manufacturing and service firms (high-tech and conventional); of those firms, the growth rates are also lower in these non-urban areas. Suburban areas tend to have less entry, growth, and survival rates than urban places but higher than rural sites.

One factor that distinguishes highly between urban, suburban, and rural areas is transport accessibility. Multiple empirical studies demonstrate convincingly that transport accessibilities may be a contributing factor to the unequal distribution of economic activities and regional growth (Alañón-Pardo and Arauzo-Carod, 2013; Geurs and Van Wee, 2004; Targa et al., 2006; Balbontin and Hensher, 2021). In a survey study in the Netherlands, Willigers and Van Wee (2011) found that public transport accessibility in the form of international high-speed trains and national transport services significantly affects business location choice. De Bok and Van Oort (2011) state that although agglomeration effects and accessibility are not the main influencing factors when relocating a company, they still convey a significant impact on the decision. This dynamic, however, requires further investigation as accessibility has not been in the focus of researchers recently.

Conclusively, the accessibility of a location seems to play a particular role for companies, which is yet clearly understood. Accordingly, for young (and established) firms, the mobility of people and goods through sufficient transport accessibility seems especially crucial. For new firms, (a) people (employees, industry experts, and others) need to be able to get to and from work; (b) resource materials need to be brought to the production place, and (c) market-ready products need to be distributed among other firms or clients (Balbontin and Hensher, 2021). Consequently, accessibility to various actors, like skilled workers (human capital), other businesses, and purchasers on a transportation level seems highly important (Audretsch and Dohse, 2004; Woo and Kim, 2021). Nevertheless, it is largely unknown if local accessibilities influence the locational choices of young firms and if this leads to more startups in highly accessible places. Opposing this concept is the consideration that startups prefer to found their company in more rural places, where land prices are affordable, there is less competition for employees, and a work-life balance is more attainable (Haisch et al., 2017). This would mean high accessibility is less critical to entrepreneurs (null hypothesis). All of these considerations lead me to conclude with hypotheses regarding the impact of accessibility on startup founding rates. I, therefore, hypothesize:

Hypothesis 1: *In locations that are generally more accessible, more startups are founded.*

When considering the human capital theory and a firm's primary necessity to hire qualified personnel, I additionally expect that the accessibility to employees, i.e., the employee population, has a higher impact on founding rates than the general population. Additionally, due to the high R&D efforts of new firms, I expect that the accessibility to researchers has an even more pronounced effect on founding rates. This leads me to the following hypotheses:

Hypothesis 2: *The accessibility to potential employees has a higher impact on founding rates than the general population.*

Hypothesis 3: *The accessibility to potential research employees has a higher impact on founding rates than the general and employee populations.*

The central questions, therefore, aim at whether the accessibility of a region is a deciding factor for entrepreneurs' location decisions. However, the mere existence of startups tells us a little about the potential other reasons for founders to locate somewhere. Thus, I want to learn about impact factors through semi-structured interviews with entrepreneurs to go beyond the correlational. I, therefore, investigate whether location decisions are driven by considering the accessibility to a firm site for the entrepreneurs themselves or their potential employees, their customers, and clients, and the transportation of goods to the latter. This will answer the research question of whether local accessibilities have an impact on startup founders when choosing a location for their businesses. In the next section, I will describe my approach for both analyses.

3.4 Data and Estimation

In this section, I describe the data used for the regression analysis of accessibility and startup founding rates, as well as the items that were part of the interview study.

3.4.1 Accessibility

As previously stated, a region's accessibility is a measure of its reachability for a specific population group, expressed as a value ranging from 0 to 1. In this study, it also considers the proportion of the general population, potential employees, or research personnel who can travel between zones using various modes of transportation and the time required for such travel. The model incorporates trip generation, destination selection, mode choice, time-of-day choice, and trip assignment (as shown in Figure 2.2 of Chapter 2).

An agent-based transportation model is used to calculate a region's accessibility. Germany is divided into 11,717 zones corresponding to all German municipalities for this measurement, with the 14 largest cities further subdivided into smaller borough-level units. Cross-border accessibility is also considered by including all neighboring countries in the calculation. The transportation network comprises roads, railways, and local public transportation modes such as suburban rails, with travel times calculated for free-flow and congested car accessibility as well as local public transport (local bus, metro, tram) and long-distance (LD) rail. For car travel, congested-car accessibility is a more realistic measure due to the presence of traffic congestion in Germany. This difference is particularly pronounced in larger cities and regions in western and southwestern Germany, where congested car accessibility is significantly lower than in free-flow traffic. In the model, short distances are those under 40km, and long-distance trips are those at or over 40km. Note that local public transport modes are employed to access long-distance modes, such as taking the bus before a train.

The calculation is based on actual travel behavior data obtained from the *Mobility in Germany Survey* (Federal Ministry of Transport and Digital Infrastructure, 2017), a nationwide travel survey conducted by the Ministry of Transport and Digital Infrastructure at intervals of five to nine years since 1970. The survey collects socio-demographic information about respondents from various groups and regions, as well as data on their trips. This information is used to generate a synthetic population and to compute accessibility between zones in Germany using a matrix system that incorporates data from the survey, the synthetic population, and the transportation network Pukhova et al. (2021). The Multi-Agent Transport Simulation model [MATSim, Horni et al. (2016)] accounts for traffic congestion in the analysis. In this study, the accessibility calculation in Chapter 2 is enhanced by distinguishing between different groups of population attractors. This results in an accessibility score for access to the general population, potential employees, and potential research employees. This is to be able to analyze the accessibility of research-intensive startups in more detail. Accessibility is found to be relatively stable over time, with minor changes and improvements observed in Germany due to lengthy road and rail construction periods. Figure 3.1 shows the distribution of congested car accessibility for different populations across Germany. In the highly accessible blue region in the far west, there are numerous medium- and large-sized cities with large populations that require improved road access. A detailed introduction of how the accessibility is calculated can be found in Chapter 2.

3.4.2 Startup Founding Rates

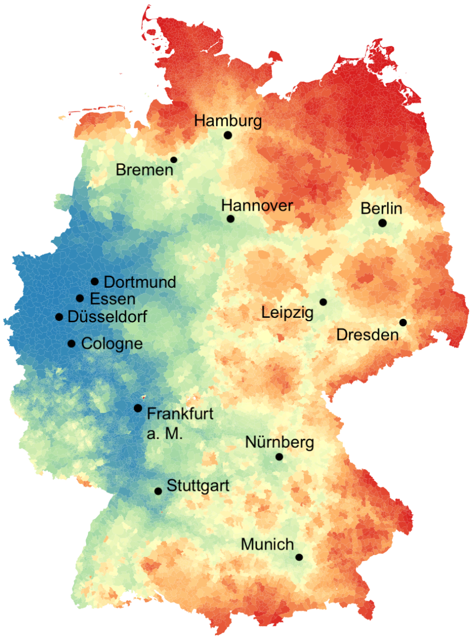
I employ a variable that represents inventive efforts in the form of a startup foundation rate as my main measurement. This data has been provided by the Leibniz Centre for European Economic Research (ZEW) in Mannheim, Germany, through their efforts to construct the largest German database regarding both established and new companies. The dataset encompasses all newly created firms in Germany between 2000-2019, and it is recorded in the Mannheim Enterprise Panel (MUP) (Bersch et al., 2014). Together with Creditreform – Germany's largest credit agency – it provides information about the commercial registry entry of firms in Germany. This dataset encompasses startups from all industry sectors. The mean value of the startup founding rate is 2.85 ($SD = 2.80$), with a minimum of zero and a maximum of 11.83. I use the logged number of this value in the OLS regression models and focus on the founding rate for the years 2000-2019.

3.4.3 Control Variables

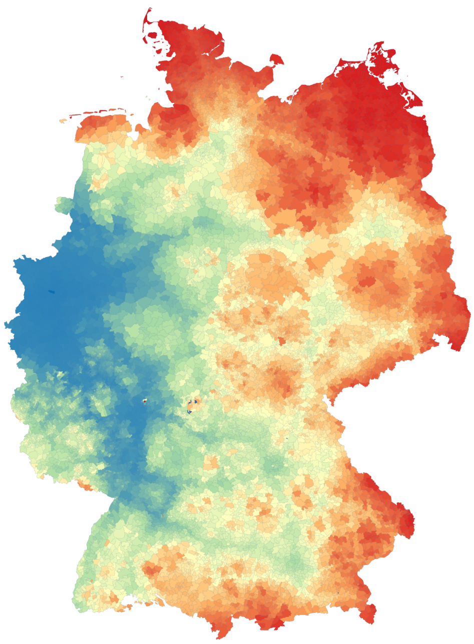
As control variables, I employ various economic characteristics of the target regions. Using Mannheim Enterprise Panel data, I can derive the (logged) total number of firms, the share

Figure 3.1: Congested Car Accessibility for Different Populations

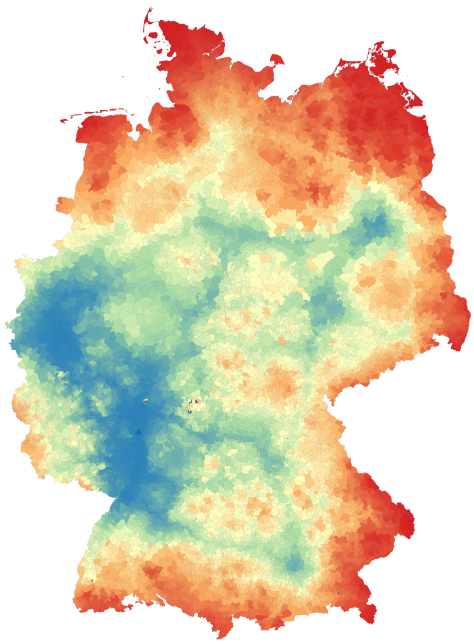
(a) General population



(b) Employment



(c) Research employment



Congested car accessibility with the general population (a) with 14 biggest city locations and (b), the employee population and (c), and the research employee population ($\alpha = 1.0$, $\beta = 1.0$). Scaling color gradient: Blue = high accessibility (1); yellow = medium accessibility; red = low accessibility (0).

of young (age under ten years) and small firms (under ten employees), and the (logged) number of manufacturing firms and service-providing firms. Another control variable is the local population size, the business tax, the size of the area, and whether a study area is at the German border. This ensures that larger zones are not over or under-accounted for accessibility-wise and that border regions with their possibly increased intra-European traffic are factored in.

3.4.4 Econometric Model

To study the link between accessibilities and startup founding rates in Germany, I estimate ordinary least-squared regression models to understand the relationship between the accessibility of a municipality and its impact on the startup rate while considering local zone characteristics. Thus, I model the startup number y for zone i such that:

$$y_i = \gamma + \delta Accessibility_i + \epsilon Accessibility_i^2 + \zeta x_i + \nu_i \tag{3.4.1}$$

with x_i capturing all control variables. I include the second-order term of the $Accessibility_i$. The outcome variable y captures the log of the number of new firms in a region within the study time frame. I employ the different accessibilities (congested and freeflow car, local public transport, and long-distance rail travel) and attraction modes (general population, employee population, and research employee population) separately.

After introducing the methodological approach used in the qualitative part of this study, I will present and discuss the quantitative results.

3.4.5 Qualitative Study Structure

In the qualitative part of this study, I use interviews with eleven startups located in Germany that were recruited through online acquisition[1]. The sampling was carried out according to previously determined criteria (rural/urban location, service/manufacturing, industry sector, and reception of private or public subsidy). In the sample, seven firms out of eleven were solely service providers, two were manufacturers, and two were both. Five firms were taking part in a subsidy program. Location-wise, nine startups are located in an urban area, one in a suburban area, and one had two locations, one suburban and one rural. Cities are, therefore, over-represented concerning the locations of the sample startups. Startup founders and employees from different regions of Germany were interviewed; however, the area in and around Munich is over-represented in the sample (five out of the eleven firms are located here). The startups interviewed were each founded by one to four people and had between one and seventeen employees. Suggestive and closed questions were avoided to avoid

[1]Interviews conducted and processed by Evi Helgert.

leading or restricting the interviewees. The on-average 25-minute interviews with 33 prepared categorical questions were conducted from March 17 to May 05, 2021, with founders and upper management employees of the eleven startups. They were conducted in the German language via video calls, which was a necessity during the ongoing pandemic at the time. A semi-structured interview method was employed without a fixed order of questioning to ensure an uninterrupted flow of speech and to receive all information available (Brinkmann, 2014). The interview answers were translated using DeepL translation software[2]. Categories were deductively formed from existing literature and structured in terms of content and scale. Table 3.1 presents the interview categories with the subitems.

Table 3.1: Interview Questions with Category Items

Main category	Item
Financing	Incubators
	Venture Capital
	Subsidy programs
Location assessment methods	Checklists, country ratings, cost-benefit analysis
Impact of regional markets	Qualified workers
	Quality of life/benefits
	Accessibility
	Suppliers
	Customer proximity
	Infrastructure
	resource materials
	Transport
	Regulatory aspects
	Tax regulations
Regional innovation intensity	Innovation intensity
	Knowledge spillovers through startups
	Local competitors
Agglomeration effects	Industrial clusters
	Knowledge spillovers through established firms
Academic startups	Knowledge exchange
	Knowledge worker pool
Social attachment	Home town
	Friends/family
Difference in urbanity	Rural region
	Suburban region
	Urban region

To control for location choice factors associated with specific startup characteristics such as industry sector, development stage, business strategy, and company success, the following descriptive variables were considered: whether startups used traditional location assessment

[2] https://www.deepl.com. Last accessed on 31.05.2023.

found to be important to firms (Arauzo-Carod et al., 2010); whether financiers and subsidy providers played a central role in the location decision due to the financial constraints faced by startups (Berger and Hottenrott, 2021); and whether tax regulations and regional legislation influenced location choice as suggested by McMullen et al. (2008). Additionally, the impact of the Covid-19 pandemic on young firms was also examined. These questions provided a comprehensive view of the location decision-making process of startups.

The interview results were noted and transcribed, omitting filler words and thinking pauses. A qualitative content analysis according to Mayring (2014), was employed to assess the interview answers. All interviews were decoded using the MAXQDA 2020 program[2]. The data was analyzed by open and focused coding similar to the manner of Grounded Theory by Glaser and Strauss (2017).

3.5 Results and Discussion

In the following section, I will present and discuss first the quantitative results and then, secondly, the qualitative results. Although many other variables potentially play a role in the location choice of startups, in this study, I focus on accessibility-related factors. However, to gather a complete picture of the surveyed startups' location choices, parts of the questionnaire were targeted at financing, local (tax) law, social ties, and innovation density reasons[3].

3.5.1 Quantitative Results and Discussion

Tables 3.2, 3.3, and 3.4 show the results for the number of startup foundations in each zone in Germany as the dependent variable. In line with Hypothesis 1, a zone's better accessibility is associated with higher startup numbers. This is reflected in statistically significant positive coefficients ($p < 0.001$) for the local startup rate and all transport modes. In more detail, the results indicate that good freeflow car accessibility is connected to significantly more local entrepreneurship behavior *(general population acc.: β = 9.84; potential employment acc.: β = 10.21; pot. research employment acc.: β = 5.16).* A more realistic assumption of congested car accessibility also results in more local startups, with coefficients of general population acc. = 9.91; employment acc. = 10.41; and research employment acc. = 4.91. Local public transport *(general population acc.: β = 7.41; employment acc.: β = 7.27; research employment acc.: β = 3.59)* and long-distance rail *(general population acc.: β = 6.75; employment acc.: β = 6.61; research employment acc.: β = 5.60)* also seem to

[2]https://www.maxqda.com. Last accessed on 21.05.2023.
[3]The aggregated responses to these questions are available upon request.

increase new venture creation. The overall similar R^2 values of around 0.44 for every group of accessibility and population indicates that indeed regional characteristics explain the different outcomes. This underlines the hypothesis that startups are significantly more founded in better accessible areas. Thus, founders seem to value good accessibility for their firm's location.

The results show that, as hypothesized, the startup rate grows with increasing accessibility. The hypotheses regarding the employment and research employment-population could not be confirmed. The coefficients for the employee population are slightly higher than the ones for the general population. Contrarily, the coefficients in the research employee population analysis are lower than the ones for the general population and employees. To better understand the results, Figure A.2.1 illustrates them graphically. It shows that with increasing accessibility, the number of startups in a region progresses accordingly. However, this relationship slightly reverses at very high accessibilities. For the control variables, we find that some of the variables impact the local startup founding rate: Capita, area size, and border proximity correlate positively with startup numbers. New firm foundings also seem to be impacted by service firms rather than manufacturing ones. However, the local business tax rate and small and young firms do not seem to make a difference.

For further robustness checks, I employed negative binomial regressions (NBR). An NBR model of the non-negative count variable, referred to as the dependent variable, is fitted with independent variables. This model is based on the assumption that the count variable of the startup founding rate is generated by a Poisson-like process, except that its variation is larger than that of a true Poisson, which is referred to as over-dispersion. Similar significant results, like with the OLS regression, further underline the correctness of my analyses (see Table A.2.1 in the Appendix section).

3.5.2 Qualitative Results

In this section, I present and discuss the insights stemming from the interviews with eleven German startups in a summarized manner. Some interview categories came with scaling systems (for example, a Likert Scale from one to five), in which case percentages of the startup shares are included. Additionally, some answers overlap within categories, which will be addressed in a general discussion of the results.

Table 3.2: OLS Regression Results for Accessibility to the General Population

Startup Founding Rate General Population Acc.	Cong. Car	Freeflow Car	Local BMT	LD Rail
Cong. Car	9.91***			
	(0.60)			
Cong. Car^2	-8.59***			
	(0.67)			
Freeflow Car		9.84***		
		(0.59)		
Freeflow Car^2		-8.40***		
		(0.66)		
Local BMT			7.41***	
			(0.59)	
Local BMT^2			-19.85***	
			(1.24)	
LD Rail				6.75***
				(0.47)
LD Rail^2				-10.62***
				(0.91)
Capita	0.60***	0.59***	0.65***	0.57***
	(0.05)	(0.05)	(0.06)	(0.05)
Manu. Firms (ln)	0.03	0.03	0.15***	0.09*
	(0.05)	(0.05)	(0.04)	(0.05)
Service Firms (ln)	0.25***	0.25***	0.26***	0.22***
	(0.05)	(0.05)	(0.05)	(0.05)
Small Firms (%)	0.24	0.24	0.06	0.17
	(0.18)	(0.18)	(0.18)	(0.18)
Young Firms (%)	0.00*	0.00	0.00**	0.00**
	(0.00)	(0.00)	(0.00)	(0.00)
Business Tax Rate	-0.00**	-0.00**	0.00	0.00*
	(0.00)	(0.00)	(0.00)	(0.00)
Area Size (ln)	0.61***	0.62***	0.43***	0.54***
	(0.04)	(0.04)	(0.04)	(0.04)
Border Area	0.54***	0.55***	0.36***	0.46***
	(0.09)	(0.09)	(0.09)	(0.09)
Constant	-5.70***	-5.61***	-4.87***	-4.78***
	(0.38)	(0.37)	(0.36)	(0.35)
R-squared	0.44	0.44	0.44	0.43
Observations	9936	9936	9936	9936

The standard error is clustered at the zone level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

3.5.2.1 Location Assessment Methods

The following interview item aimed at finding out whether startups applied traditional location assessment methods. The founders in the sample, however, stated that they did not use these traditional approaches. Nevertheless, seven startups in the sample created their own

Table 3.3: OLS Regression Results for Accessibility to the Employee Population

Startup Founding Rate Employee Population	Cong. Car	Freeflow Car	Local BMT	LD Rail
Cong. Car	10.41***			
	(0.58)			
Cong. Car^2	-8.79***			
	(0.65)			
Freeflow Car		10.21***		
		(0.57)		
Freeflow Car^2		-8.49***		
		(0.64)		
Local BMT			7.27***	
			(0.54)	
Local BMT^2			-18.07***	
			(1.01)	
LD Rail				6.61***
				(0.43)
LD Rail^2				-9.49***
				(0.77)
Capita	0.59***	0.58***	0.65***	0.56***
	(0.05)	(0.05)	(0.06)	(0.05)
Manu. Firms (ln)	0.03	0.02	0.15***	0.09
	(0.04)	(0.04)	(0.04)	(0.05)
Service Firms (ln)	0.25***	0.25***	0.28***	0.22***
	(0.04)	(0.04)	(0.05)	(0.04)
Small Firms (%)	0.25	0.25	0.01	0.16
	(0.18)	(0.18)	(0.18)	(0.18)
Young Firms (%)	0.00	0.00	0.00***	0.00*
	(0.00)	(0.00)	(0.00)	(0.00)
Business Tax Rate	-0.00**	-0.00**	0.00	0.00*
	(0.00)	(0.00)	(0.00)	(0.00)
Area Size (ln)	0.63***	0.63***	0.40***	0.55***
	(0.04)	(0.04)	(0.04)	(0.04)
Border Area	0.57***	0.57***	0.38***	0.49***
	(0.09)	(0.09)	(0.09)	(0.09)
Constant	-5.77***	-5.66***	-4.61***	-4.77***
	(0.37)	(0.37)	(0.36)	(0.35)
R-squared	0.44	0.45	0.44	0.43
Observations	9936	9936	9936	9936

The standard error is clustered at the zone level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

location assessment criteria. These criteria were: Accessibility for one of the startups or 9%, price-performance in comparison to size (for two firms or 18%), incubators (18%), existing network of founders at the location (9%), logistical reasons (9%), location of founding members, locations with the most customer potential (9%), implementation of a most successful new acquisition (9%), a decision due to personal ties (9%). In the following categories, these

Table 3.4: OLS Regression Results for Accessibility to the Research Employee Population

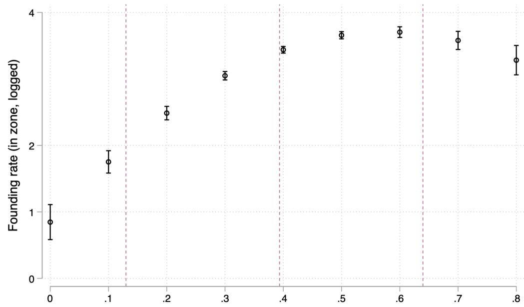
Startup Founding Rate Research Employee Population	Cong. Car	Freeflow Car	Local BMT	LD Rail
Cong. Car	4.91***			
	(0.54)			
Cong. Car^2	-3.29***			
	(0.54)			
Freeflow Car		5.16***		
		(0.52)		
Freeflow Car^2		-3.39***		
		(0.50)		
Local BMT			3.59***	
			(0.61)	
Local BMT^2			-12.41***	
			(1.37)	
LD Rail				5.60***
				(0.44)
LD Rail^2				-7.55***
				(0.78)
Capita	0.61***	0.60***	0.68***	0.58***
	(0.05)	(0.05)	(0.06)	(0.05)
Manu. Firms (ln)	0.05	0.04	0.12**	0.09
	(0.05)	(0.05)	(0.04)	(0.04)
Service Firms (ln)	0.23***	0.24***	0.24***	0.23***
	(0.05)	(0.05)	(0.05)	(0.04)
Small Firms (%)	0.10	0.11	-0.02	0.10
	(0.18)	(0.18)	(0.18)	(0.18)
Young Firms (%)	0.00*	0.00*	0.00***	0.00**
	(0.00)	(0.00)	(0.00)	(0.00)
Business Tax Rate	-0.00**	-0.00**	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Area Size (ln)	0.57***	0.58***	0.41***	0.53***
	(0.04)	(0.04)	(0.04)	(0.04)
Border Area	0.64***	0.66***	0.36***	0.48***
	(0.10)	(0.10)	(0.09)	(0.09)
Constant	-4.79***	-4.79***	-4.30***	-4.56***
	(0.35)	(0.35)	(0.37)	(0.35)
R-squared	0.43	0.43	0.43	0.43
Observations	9936	9936	9936	9936

The standard error is clustered at the zone level. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

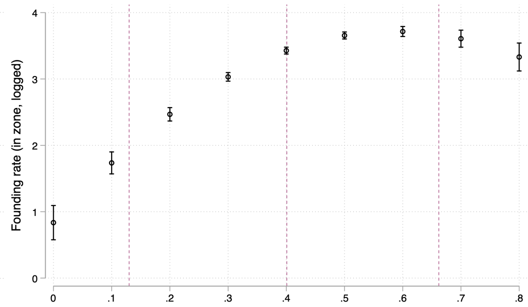
reasons for location choice are included for the respective firm that mentioned them, and they are further investigated.

Figure 3.2: Result Graphs for the General Population and Employee Population Accessibility

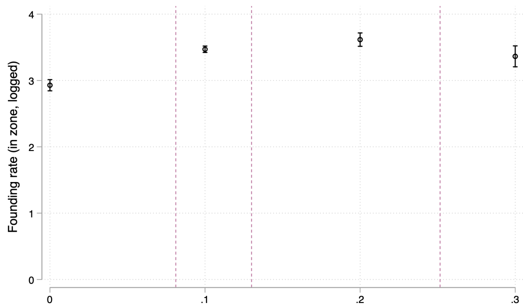
(a) Gen. Pop.: Cong. car



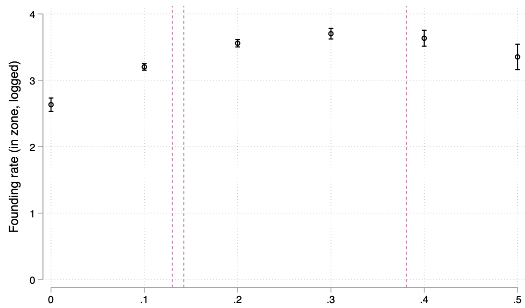
(b) Gen. Pop.: Freeflow car



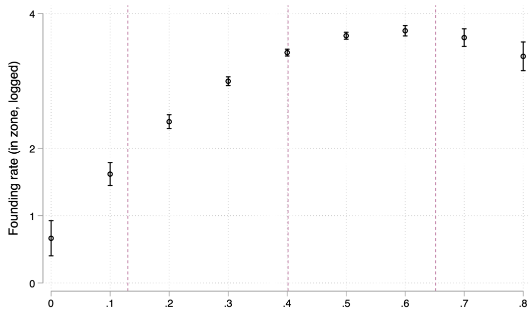
(c) Gen. Pop.: Local BMT



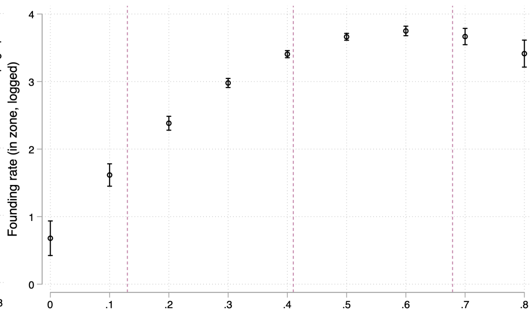
(d) Gen. Pop.: Long distance rail



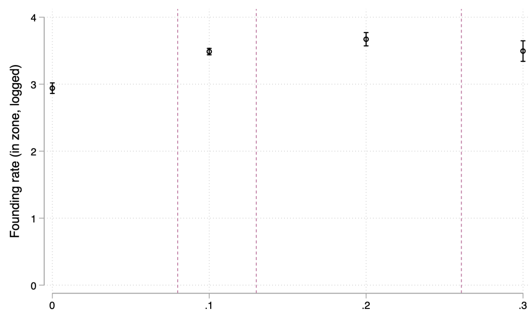
(e) Emp.: Cong. car



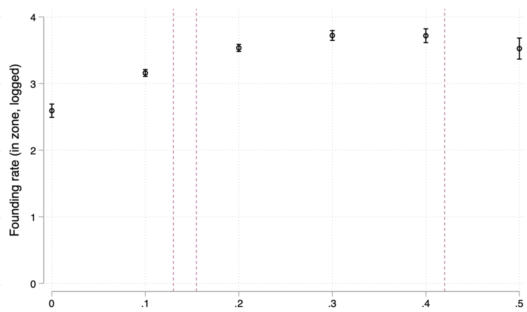
(f) Emp.: Freeflow car



(g) Emp.: Local BMT



(h) Emp.: Long distance rail



Accessibility weights at $\alpha = 1.0$, $\beta = 1.0$. Average marginal effects of the variable with 95% CIs. Dotted lines mark the accessibility mean, median, and 95th percentile.

3.5.2.2 Access to Materials

Access to resource materials was a requirement for the manufacturing startups in the sample (six out of eleven). These startups reported that physical proximity to materials facilitated communication and simplified deliveries. In the technology sector, foreign suppliers from China were also mentioned, with the disadvantage of time-consuming communication, which was, however, mostly well-managed by the Chinese supplier. Two startups in this study required traditional German agricultural materials and standardized reusable glass bottles for packaging. They also need to locate where there is proficient groundwater quality, as this is essential for the taste of their product. Good access to resource materials through physical proximity was considered important, with materials being grown near the firm and warehouses and cooling areas located within a 50km (ca. 31 miles) radius.

In conclusion, access to materials plays a vital role in site selection for manufacturing startups. Locations that offered favorable opportunities for the procurement, storage, and processing of materials were preferred. Some startups also sourced resource materials from abroad due to lower costs. Cities were described as unprofitable due to high costs, with materials having to be sourced from surrounding areas and rural regions.

3.5.2.3 Transportation

Transportation, in general, was rated as highly relevant by startups in sales and production (five out of eleven), while those working primarily digitally rated its relevance as low. One logistics startup rated transportation as moderately relevant because it did not yet deliver to customers but anticipated that it would become central in the future due to the design of its product. One firm stated that transportation is dependent on an efficient connection to potential customers, and thus, a central location in Germany would be chosen to ensure short paths to a large share of their client population. Another startup indicated that transportation was highly significant due to their need for a weekly delivery of their product. Another firm cited transportation as a major cost factor due to the delivery of their heavy-weight product. However, it was able to significantly reduce transportation costs through local connections and cooperation with an electric car company, which they attributed to the friendly local mentality of the region. A third firm also cited transportation as very relevant and had relocated to improve proximity to warehouses, reducing transportation and delivery costs through their choice of location. One startup had designed their product for easy transport to minimize transportation costs.

While transportation played a minor role for many digitally-focused startups in the sample, it was rated highly relevant by startups in sales and production. Although transportation was considered necessary, it only had a decisive impact on location choice for two of the surveyed startups due to its potential to reduce transportation costs. The respective industries of these startups also influenced this.

3.5.2.4 Customer Proximity

Of the eleven startups surveyed, seven rated customer proximity as highly significant. Two startups each rated customer proximity as being of medium and low relevance. One startup, however, selected its location based on proximity to customers in the railroad, automotive, and industrial sectors. This firm reported that follow-up orders depend on the personal relationship between the sales consultant and the customer. Another startup rated customer proximity highly important due to its impact on communication with their end users and business customers. For a manufacturing startup, local proximity to customers facilitated product delivery and was also favorable due to proximity to automobile manufacturers. Another startup which is in the beta phase with their app product, rated customer proximity as highly important for building personal relationships with potential app testers. Proximity to other businesses and employees of nearby office buildings also seems to be positively contributing. Other entrepreneurs worked closely with their customers, providing and maintaining hardware products and holding on-site training sessions. For another startup, customer proximity was important for brand building and distribution to end customers through small vendors, and another stated that proximity to customers was crucial in their personally structured sales field, where face-to-face meetings were essential for building customer relationships. Some found that physical proximity will become less crucial in the future as they expand their business digitally across Europe. They also rated customer proximity as less important for their company.

In summary, slightly more than half of the startups surveyed rated proximity to customers as essential, and some chose their location based on this factor. Proximity to customers was cited as advantageous for building personal relationships, facilitating communication, simplifying delivery, supporting brand image building and distribution channels, and enabling collaboration. This is potentially more important to startups than established firms with a solid inter-regional customer base.

3.5.2.5 Commute

In this section of the interview study, founders were asked about their employees' commuting habits, including modes of transportation, average commute time, and satisfaction with their journey. Two startups reported that their employees primarily worked from home and did not commute. Another startup reported using public transportation and bicycles as their main modes of travel. The remaining startups reported using a combination of cars, trains, buses, metro, tram, bikes, and walking. One founder reported living only 500 meters (0.31 miles) from the office and being very satisfied with the short commute. Their employees used various modes of transportation, and the startup was easily accessible due to its proximity to a highway. Another entrepreneur was also satisfied with the company's location due to the short commute. One startup reported a 15-20 minute car commute to their production location and a ten-minute bike ride to a customer-serving selling point. This firm also reported occasionally working from home and being satisfied with accessibility and mobility options. Other firms reported using cars, bicycles, or public transportation to commute to the office or work from home. The perceived dangerous traffic situation for bicycles was rated negatively, while sufficient public transport connections and access to bus/metro/tram stations were seen as positive. One entrepreneur in a suburb near a large city reported difficulty recruiting employees due to poor accessibility and long commutes. This entrepreneur expressed a desire to relocate to the city center in the future due to dissatisfaction with the current location.

In summary, the results of the interviews suggest that startups were more satisfied with their location if it was easily accessible and employees had short commutes of approximately 10-20 minutes. A desirable location offered multiple transportation options, including public transportation, highway access for cars, and bicycle paths. These criteria applied primarily to urban locations. Almost all startups reported that their employees worked both from home and in an office space, with spontaneous switching that the ongoing COVID-19 pandemic may have enhanced at the time.

3.5.2.6 Infrastructure

In this section of the interview study, founders were asked about the importance of infrastructure, including transport connectivity, proximity to universities and innovation hubs, and hospitals as potential cooperation partners. One startup reported working with a nearby university and hospital and receiving support from an industry-specific accelerator, making local infrastructure highly important for them. Another startup was influenced by a funding program offering office space in a specific location. For another firm, infrastructure offering good opportunities for small vendors was crucial for distribution and business growth. Other entrepreneurs negatively evaluated the infrastructure in their suburban location and cited better infrastructure as a factor in their decision to relocate to an urban region. In contrast, connectivity was highly relevant for other startups in this study. Factors cited as important for good transport connectivity included a main intra-city train line (9% of surveyed firms), highway access (27%), public transportation (36%), airports (36%), and large train stations with connections to major cities. Only one startup reported that infrastructure had no significance for their choice of location as they solely worked from home. In the literature, good infrastructure also encompasses political, social, economic, and legal systems. The startups in this study were located in Germany, offering an infrastructural and safe environment for company formation. This aspect was not proactively mentioned in this research, potentially due to the perceived political safety in the country.

3.5.2.7 Qualified Workers

In this survey, young firms were asked about their personnel structure. Six out of eleven startups reported having employees. Some startups also reported using the services of working students, interns, freelancers, external development teams, experts, consultants, and supporters from the university environment. A qualified workforce was, therefore, highlighted as a significant factor in the choice of location. Special attention was paid to the level of education and professional qualifications of potential talent.

Several startups reported that their location needed to offer a pool of qualified workers. One startup expressed a desire to recruit graduates from a specific university due to the availability of a highly qualified workforce. The recruitment process via universities was identified as necessary for attracting qualified candidates. Recruited employees were often already located in the same region as the startup. Five startups in the sample frequently mentioned technical and business administration fields of study. One firm recruited through a nearby university chair in addition to traditional LinkedIn or Indeed advertisements, while another used its own human resources tool. This firm preferred to recruit employees from their hometowns as well as national and international employees. Three other startups also mentioned international employee recruitment due to lower wage options. Two firms recruited workers through their network, and two others reported employing family members and friends. One company cited the long commute and limited leisure activities at their suburban location as negative factors in employee recruitment. Other location factors hampered employee recruitment included: Racism, poor accessibility, less qualified workers, and rural regions with a low population.

In summary, all startups frequently mentioned skilled labor as an essential factor in site selection. Close-by universities were cited as an indicator of a qualified, well-trained, and specialized workforce. Recruited employees often came from the same region as the startup and were sometimes family members or acquaintances. Founders' personal networks and university connections were successfully used for employee recruitment.

3.5.2.8 Quality of Life

In this section of the interview study, founders were asked about the regional advantages they advertised when recruiting potential candidates. Multiple responses were possible in this section. One firm reported offering a public transportation ticket as a benefit for employees. Two other firms advertised the infrastructure and airport hub at their location. Another firm communicated the advantage of an international society in a large city, particularly for skilled workers from abroad who could quickly feel at home. Three other entrepreneurs cited the open mentality of the people and the potential for social and fast integration as positive aspects of their location. One startup advertised the low cost of living in their suburban location. Two other firms cited parks, proximity to mountains, and good recreational opportunities as factors contributing to a good quality of life for workers at their location. Leisure facilities (especially for young people) and quality of life at the location were the most frequently mentioned advantages in the interviews. A media hub in one city and cultural offerings in another city were also mentioned. Five firms emphasized the good standard of living in their cities.

In summary, the startups in this study focused on attracting qualified employees by advertising regional advantages and benefits for employees. Due to low costs, the surveyed startups often employed younger people with different needs than experienced workers. As such, advertised regional advantages were often related to lifestyle and recreational opportunities in cities. Infrastructure, social contacts for new employees, low cost of living, local recreation areas, and quality of life were essential factors for startups at their location.

3.5.2.9 Knowledge Spillovers and Industry Clusters

As for any knowledge spillover and networking between young firms, nine startups stated that they often exchange information with other startups. Two startups reported infrequent knowledge exchange. One startup reported active engagement, collaboration, and mutual support with nearby startups, including using another startup's human resources service and hosting informative lectures for other startups and students. This way, the startups can support each other with success strategies and tips. Three young companies also see immense advantages through the network of startups in their urban location. Another company reported connecting with a network of founders, forming strategic partnerships, and exchanging recommendations for agencies or lawyers to avoid repeating other entrepreneurs' mistakes. Digital exchange enabled cross-regional information sharing, as reported by four founders. Exchange topics included potential investors, pitch preparation, and technical and business-relevant knowledge from industry-similar and experienced startups. One startup reported exchanging information with similar young firms regionally and nationally.

As for knowledge exchange with established companies, the survey revealed that this is essential for eight firms, while three reported infrequent or no exchange. Nearly half of the surveyed startups reported either few or many established firms in their vicinity, with the remainder reporting an average density. Proximity to established firms facilitated contact establishment, easy business-to-business product delivery, and project collaboration. One startup reported working with smaller regional business partners and larger national partners. Another startup is located near established firms due to favorable production factors. One startup reported frequent exchange and collaboration on industry-specific topics and app testing with local vendors. Remote communication via personal networks was also reported, as some startups reported close and supra-regional exchange with established companies across Europe. Two firms bemoan limited information exchange due to the Covid-19 pandemic.

In summary, many startups reported positive relations and cooperation with other young firms and established companies. Networking and mutual support were common themes, particularly among incubators promoting close contact between founders. Recommendations, professional knowledge, success strategies, and collaborations helped the interviewed startups build their businesses. Exchange extended beyond local startups to include nationwide (young) firms in their industry or personal network. However, some bemoaned limited information exchange due to the Covid-19 pandemic.

3.5.2.10 Academic Spin-offs

Of the surveyed startups, six were located near the Alma mater of at least one founder. Four startups reported no proximity to their home university or a lack of academic background among founders. Home universities influenced location choice through funding programs for some startups, while others chose their location independently of universities. Academic startups reported positive proximity and cooperation with universities and colleges. Startups that received funding and were founded by a university confirmed the importance of their home university. Some startups cooperated with universities other than theirs, facilitated by personal or professional contacts with professors and researchers, promoting knowledge spillovers. Reasons for locating near universities included access to scientific knowledge, qualified researchers, high education level, proximity to target customers, contacts and friends near the home university, university networks, and university reputation.

3.5.2.11 Regional Differences

Regarding regional differences, the study revealed that most surveyed startups were located in urban areas and satisfied with their location. Two startups were located in suburban areas and one in a rural area. Urban advantages included good infrastructure and connectivity, proximity to suppliers and customers, localized investors and universities, qualified workforce, recreational opportunities, internationality, and quality of life. Disadvantages included high competition density, expensive location, lack of local recreation areas, congested traffic, high production costs, and high labor wages. Due to the COVID-19 pandemic, home office activities were perceived as disadvantages of the city due to, on average small urban housing. Suburban startups reported difficulty recruiting employees due to poor infrastructure, long commutes, and lack of leisure activities. One startup considered relocating due to the negative aspects of the suburbs. Another startup was satisfied with its rural location, as for some, factors that can be found in the countryside, like forest and greenery, are important. Some startups valued factors in rural areas such as the natural environment and higher quality of life. One manufacturing company was satisfied with its suburban location, while one technology company from the suburbs desired relocation to the city. Online startups stated they were rather independent in their choice of location. Personal preferences for after-work activities also influenced the entrepreneurs' regional location choice immensely.

3.5.2.12 Digitization

As mentioned in the previous category, technology-based startups reported that location was less important due to digital operations. Three startups were developing smartphone apps that valued automation and remote work as satisfactory regardless of location. One startup's overall business goal was the complete remote and location-independent operation, with employees, financiers, and customers across Europe and positive prior experiences with digital work. Another company allowed software engineers to work entirely remotely during the COVID-19 pandemic. One startup viewed remote work as a prospect for attracting more employees across Europe. The pandemic forced another startup to adopt remote work, leading to a successful online business operation. Nevertheless, they would like to handle customer service locally and still have the opportunity to work together in their office. Some startups identified physical proximity to strategic industrial clusters as necessary for personal connections with other firms, which was, in turn, solved remotely by one young firm. Most startups relied on a hybrid online and offline connection model, even if their service was completely offered online. Nevertheless, personal face-to-face relationships were considered significant in the business world to almost everyone participating in the study.

3.5.3 Discussion of Interview Results

The reason for undergoing this additional interview study was to uncover underlying reasons for startups to locate in accessible areas. Although accessibility was not the primary factor for startups to locate where they are, accessibility was seen as an instrument for deciding location factors. The availability of a qualified workforce was identified as the most significant location factor among startups surveyed in this study. Additionally, social ties with research institutions were found to be influential, with founders collaborating with researchers through funding programs and partnerships. This factor is strongly associated with the presence of universities and the founders' home countries, as university graduates constitute a qualified workforce, and employees are often recruited from personal networks.

Another factor for locating close to their Alma mater was that funding programs specifically target university alums and also provide office space in universities (see *EXIST* (Kulicke, 2021)). Startup accelerators and incubators at the location were also rated positively by young firms regarding innovation infrastructure. Participation in an incubator program is valuable to startups not only for the various financial and knowledge exchange opportunities but also exposure to potential clients and customers. These factors collectively contribute to the availability of qualified workers. This is also essential for the location's overall livability. A location's quality of life value was frequently cited by startups concerning their chosen region. Additionally, an open and international society, recreational areas and parks, low living costs, and good infrastructure were identified as essential factors. Results suggest that quality of life and recreational opportunities for young employees need to be considered when selecting potential settlement areas. Control variables such as regulatory aspects, tax regulations, and classic location evaluation methods were found to have a lower impact on location choice. This result could be due to the sample's relatively small startups in terms of employee numbers. Smallness is a typical startup indicator; however, entrepreneurs who are experienced with startup founding might focus on these regulatory aspects more. Some firms created their own location assessment methods indicating that the location choice, in general, is an important one to founders besides their other business strategies. Proximity to customers was identified as an essential location factor for manufacturing startups, with personal contacts and physical meetings facilitating better customer access. For digitally working startups, client interaction was less relevant; nevertheless, personal contact with other firms for knowledge exchange was highly valued. This indicates that also firms that could conduct their business entirely online, accessibility to other people and companies is a necessity to them. Founders also targeted innovation-intensive regions near other startups, valuing face-to-face interactions for knowledge exchange and networking. Agglomeration effects and strategic industrial clusters were also advantageous for startups due to the more attainable establishment of cooperation and interaction with established companies. The trend towards digitization was found to significantly influence the location choice of startups surveyed in this study, with some already operating entirely remotely and independent of location. However, it should be noted that the COVID-19 pandemic and associated contact restrictions mandated remote work for many startups. The majority of startups expressed a preference for hybrid models that enable both digital and on-site work. Customer contact and everyday work were reported to be facilitated by working together in the office. This entire dynamic indicates that human-to-human interaction will remain highly relevant in future scenarios. Proximity to resource materials, suppliers, and transport was found to be relevant location factors only for manufacturing companies. Supplier selection was partly regional and partly global for financial reasons. However, communication with global suppliers could be difficult and flexibility limited. Regional suppliers were preferred for simplified short-term deliveries, physical proximity, uncomplicated communication, and good quality. Firms also preferred to locate close to production resources to reduce transportation costs and facilitate processing. However, transportation costs cannot always be minimized through location choice; thus, cost-benefit balancing seems to be essential here. As a result, some regional factors may become less relevant in the future due to increased digitization, but their importance will not be completely diminished. Other factors like good internet connectivity may become more critical in location choice. Regarding policy, barriers to entry should be reduced through digital, non-bureaucratic legal and advisory solutions. Due to contact restrictions and government requirements during the COVID-19 pandemic, many companies chose to work from home, which may limit the representativeness of this study in non-pandemic situations. Accordingly, startups value a location easily accessible through good local public transport infrastructure and highway access. This was particularly true in urban regions, where many startups in this sample chose to settle. Cities offer several positive influencing factors, such as universities, qualified workers, proximity to suppliers, customers, investors, and an international startup ecosystem. Despite negative aspects such as higher competition, cost-intensive location, and lack of recreational areas, results suggest that settling in urban regions positively impacts startup formation and development. In suburban and rural areas, poor accessibility and difficult employee recruitment were identified as disadvantages, while close access to resource materials was a positive factor. However, the over-representation of city startups in the sample may limit the generalizability of these findings.

Overall, results from interviews with eleven German startups suggest that accessibility is not the only important factor in location choice. However, factors directly impacted by local transport accessibility, such as short commutes, regional employee recruitment, access to resource materials, and customer proximity, were frequently mentioned.

3.6 Conclusion

Location factors and their impact on established and newly founded firms have been the focus of innovation and entrepreneurship researchers for many years. My study builds on existing literature by focusing specifically on new companies, which play an essential role in innovation and regional development (Haltiwanger et al., 2016; Schneider and Veugelers, 2010). This research contributes to research on variances in regional startup firm settling by examining the role of location-based accessibility and builds on previous research on location factors for young firms (Audretsch and Dohse, 2004; Woo and Kim, 2021). This is also undergone due to ambiguous results on whether young firms move to locations with more benefits or whether they tend to locate where their founders originated (Hellwig, 2023). An agent-based modeling approach using a fine-grained zone system of Germany was employed in order to measure accessibility, taking into account different modes of transport as well as traffic congestion on roads. The resulting accessibility ratings capture a location's potential access to human capital, with population, potential employees, and potential research employees being used as the main attractors. Accessibility by public transport (bus, metro, tram, long-distance rail) and by car were distinguished. The descriptive analysis demonstrates that locations vary considerably in terms of accessibility and that it encompasses more than merely an urban/rural dichotomy. Subsequently, I investigated whether transport accessibilities impact the local startup founding rate. The econometric results show that the accessibility of a region seems to be highly important for entrepreneurial startups, as the number of young firms is significantly higher in better-accessible regions. This insight holds true when looking at the accessibility of regions for the general population, potential employees, and potential research employees. However, this effect vanishes in highly accessible regions, indicating that accessibility in these locations is less influential on founding activities. To further understand these quantitative results, I analyzed results from eleven interviews with newly founded German firms on their choice of location. It was, therefore, investigated a young firm's location choice and whether the accessibility influenced this choice. The results indicate that although accessibility is not at the top of the entrepreneurs' minds, the benefits of working in an accessible area were highly valued. Therefore, founders considered how the location of their business is impacting their commute, accessing resource materials, employment of talents, and the distribution of their product. Thus, even in a country like Germany, which is structured in a decentralized manner, the startups in the sample seemed to favor highly accessible regions with a developed public transport infrastructure.

In a follow-up study, more young firms in rural areas could give further insights into why they chose against an urban environment. Additionally, some observed startups, especially the ones that predominantly work in the software sector, were provided office space by their startup subsidy program or worked digitally without production or transportation costs. Focusing on firms dependent on these criteria in follow-up studies would provide valuable insights into these dynamics. Including the industry sector of the startups in the regression analysis could also enhance future analyses. Additionally, some location factors in this study were closely related or mutually dependent. These interaction effects need to be considered in future surveys. Overall, this study has provided new insights into the correlation between transport accessibility and where and why startups locate at a specific place, emphasizing that even in today's digital world, location availability still affects entrepreneurial activity. This information is valuable for founders when considering opening and starting up a new company and looking for office or production spaces. Better accessibility could enhance the availability of qualified workers and necessary materials. Additionally, these insights are valuable not only for future entrepreneurs but also for policymakers concerning providing mobility options in less accessible places to boost local entrepreneurship.

4 | The Role of Location-based Accessibility for the Effectiveness of Startup Subsidies

4.1 Abstract

Startup companies and their innovative products and services contribute to technological progress. However, startups face many challenges related to the liability of newness. Therefore, public policies aim at providing support, for example, through startup subsidies to overcome early-stage financing constraints which may hamper investments and firm development. In this study, we investigate how a startup's location influences the effectiveness of such public support. We build on detailed data from a country-wide agent-based transport model used to derive local accessibilities for different modes of transport while accounting for road congestion. Theoretically, the link between local accessibility and the effectiveness of startup subsidies is ambiguous. Providing support to firms in less accessible regions may be more effective if it helps compensate for the location's disadvantages. However, targeting support to better accessible places could be more effective if subsidies and accessibility are complements, i.e., startups can make better use of additional resources in better accessible places. Results based on detailed information on founder and startup characteristics show that better accessibility, especially better accessibility of a highly-skilled workforce, indeed increases the effectiveness of subsidies. In particular, we find subsidies trigger more additional own-financed R&D when startups have better access to potential R&D employees. For the effects on non-R&D-related outcomes, local accessibility does not seem to matter.

4.2 Introduction

As already mentioned in the study of Chapter 3, young firms have been in the focus of economic and innovation researchers because of their vital role in innovating and developing

Author contributions: This chapter is joint work with Hanna Hottenrott.

novel products and services and driving regional employment (Acs and Audretsch, 1988; Audretsch and Keilbach, 2004; Haltiwanger et al., 2013; Schneider and Veugelers, 2010; Pellegrino et al., 2012). However, financial resources make or break a new firm's success. Most young firms need external financial resources to develop their business idea and grow (Cassar, 2004). Initially, startups need to invest in machinery, components, research and development (R&D), employees, and office space without being able to draw from previous cash flow. Technological and market uncertainties are additional hurdles. Therefore, in the beginning, limited financing can result in slower growth and underperformance of a startup, explaining why only a fraction of new firms succeed. To avoid this pitfall, public subsidy programs have been created to support young firms with high innovation potential (Lerner, 2020).

While the evidence is still relatively scarce, most existing studies show that public funding seems to positively impact firm growth (Cantner and Kösters, 2015; Howell, 2017; Hottenrott and Richstein, 2020; Zhao and Ziedonis, 2020). However, it remains ambiguous under which conditions such programs are most effective. Founder and firm characteristics may certainly matter, but the program design as such also likely plays a role.

Another critical dimension is the location of the startup. For example, some programs favor urban areas with more universities, banks, and innovation hubs (Cumming et al., 2006; Rephann, 2020), and some programs are limited to specific locations, such as the city or county that provides the grant. Some programs also target their support to specific types of founders who tend to locate in certain locations. For example, the *EXIST* program (Kulicke, 2021) is a public subsidy scheme that exclusively supports academic founders who collaborate with universities in Germany. Although many programs have a regional dimension, it is largely unexplored how the location of a company to which the support is provided matters for the policy's effectiveness.

Empirically, it has been clearly shown that location matters for innovation (Feldman, 2004; Black and Henderson, 1999; Glaeser and Gottlieb, 2009). While location factors have been studied extensively with regard to established companies, their impact on startups is not as clear yet (Hottenrott and Lopes-Bento, 2014; Nilsen et al., 2018). Studies found that location characteristics, especially access to human capital, impact the innovation performance of firms (Czarnitzki and Hottenrott, 2009) and that local knowledge spillovers through interactions play an essential role (Fudickar and Hottenrott, 2019). Moreover, superficial location characteristics, such as the distinction between urban and rural areas, may not be sufficient to capture relevant aspects of a new firm's location. For instance, Fritsch and Wyrwich (2021a) find that in most OECD countries, innovative activity happens not only in larger cities but also outside of metropolitan areas. This insight is also in line with Berkes and Gaetani (2021), who document that there is more unconventional innovation in urban areas of the United States and a significant amount of patenting in relatively remote locations. This may be explained by the availability and nature of innovation-relevant capital and resources in these locations. Therefore, measuring the transport accessibility of a location rather than relying on a simple urban-rural dichotomy may help to capture innovation-relevant aspects of a particular place.

While it is ex-ante unclear whether the effectiveness of startup support depends on the location, one may theorize that the effectiveness is higher in places where the constraints and hence the need for support is accordingly higher. This dynamic may apply to less accessible places. Moreover, the more accessible a location, the more prone it may be to high competition for resources, congestion, a general over-use of infrastructure, and rising prices for renting and wages (Gertler et al., 2022). On the other hand, startups may be able to make more effective use of additional resources in locations that are better accessible as a result of lower transaction costs and the location's provision of complementary infrastructure and resources. Finally, while the location may matter for innovation in general, it may not make a difference in support effectiveness. Crass et al. (2019) investigate how the geographical clustering of subsidy recipients impacts the effectiveness of public innovation support programs for established companies and conclude that regional clustering has no impact on the program's effectiveness. Regardless, geographical clustering and accessibility are different concepts. Therefore, it remains unknown which of these two arguments prevails, whether they outweigh each other, and which role potential congestion plays.

This study contributes to closing this gap in our understanding of the effectiveness of public startup support. For our empirical study, we employ a fine-grained measure for accessibility that captures car transport, public transport, and trains for 11,717 micro-geographic zones in Germany. We derive different measures of a location's potential accessibility depending on whether we intend to capture how accessible a location is to the general population, the workforce (employees), or R&D employees (employees with research-related jobs). Since one may argue that potential accessibility might overestimate the accessibility of zones with more opportunities (i.e., have a higher attractiveness) because there is more competition for these opportunities. Therefore, we construct *competitive accessibilities* that discount places with high competition between seekers of these opportunities. We combine these indicators with data from newly founded companies surveyed via the IAB/ZEW Startup Panel. This data provides information on the financing of the startups, including details on public sources. It also requires various characteristics of the startups, such as team/one-person founding, gender distribution in a team, age, number of employees, revenue, profit, and others. We first estimate the average treatment effects from receiving startup support using econometrics matching techniques that take into account that the subsidy award is highly selective. In particular, we replicate the analysis by Hottenrott and Richstein (2020) for an updated and larger sample of German startups. Subsequently, we perform a treatment effect heterogeneity analysis (Hottenrott and Lopes-Bento, 2014; Hottenrott et al., 2017). In this dissection, we test whether the magnitude of the individual treatment effect depends on the accessibility of a startup's location. The results confirm that there is indeed a positive average treatment effect of public subsidies on various outcomes: R&D spending, investment, revenues, innovation, and survival. Nevertheless, we find little impact of accessibility on most of these outcomes. However, startups in locations with better accessibility to R&D employees and higher competitive accessibility show more additional R&D efforts (expenditures and R&D employees) and a higher probability to innovate in response to public support. Thus, we find subsidies trigger more additional own-financed R&D when startups have better access to potential (R&D) employees. This suggests that better accessibility, especially better accessibility of R&D workforce, indeed increases the effectiveness of startup subsidies. For non-R&D-related outcomes, local accessibility does not seem to matter for the magnitude of the treatment effect.

In the following, we discuss how subsidies, such as grants and loans, may help startup companies in the form of financing of the founder's salary and investments in R&D of their product or service. We subsequently discuss relevant outcome indicators such as future product innovations, revenues, and the probability of survival. Next, we describe the primary measures used in the empirical analysis, the calculation of accessibilities based on an integrated land-use transport model (Geurs and Van Wee, 2004), and how the startup support is defined. We derive a set of hypotheses to be tested empirically and set out the method of analysis. Finally, we present and discuss the results.

4.3 Theoretical Framework and Hypotheses

New firms have the potential to generate and diffuse transformative innovations that require organizational flexibility and break with existing technology paths (Huergo and Jaumandreu, 2004; Plehn-Dujowich, 2009; Lebdi, 2015; Bouncken et al., 2021). Successful innovation in young firms is, however, not guaranteed. While the societal returns to entrepreneurial activities are potentially significant, so are the risk and barriers for founders. Companies entering markets with new complex products and services are especially prone to suffer from the burden of novelty (Hottenrott et al., 2018).

Unlike mature firms, which have a track record of past activities, new firms are more likely to fail due to uncertainty related to the technological viability and the market success of their products, uncertainty about their management capacity as well as their ability to battle established and new competitors (Ostgaard and Birley, 1994). Evidence – primarily from the US – indicates most new businesses close within the first few years, and only a few grow such that they generate a significant number of jobs (Hurst and Pugsley, 2011; Haltiwanger et al., 2013; Levine and Rubinstein, 2017).

In light of declining startup numbers in several European countries and the United States and highly skewed distributions in new firms' growth rates (Decker et al., 2016; EFI, 2017), governments increasingly aim to support founders in overcoming initial hurdles (Lerner, 2020). The fact that entry and growth barriers appear to persist despite a multitude of policy programs in place calls for research evaluating the effectiveness of the support instruments used. In particular, it seems crucial to better understand the conditions under which support programs are most effective.

While the generally positive effects of public support for startups have been investigated in a number of recent studies (Almus, 2004; Colombo et al., 2013b; Howell, 2017; Hottenrott and Richstein, 2020; Grilli et al., 2017), critical dimensions that facilitate possible higher effectiveness per Euro spent on these programs remain unexplored. Since the location of a new company matters for its performance, it may also matter how much use founders can derive from additional support. To investigate the mechanisms through which public subsidies affect activities in young companies, Hottenrott and Richstein (2020) matched newly founded firms that are either recipients or non-recipients of subsidized loans and grants and performed an analysis on various firm and founder characteristics. They find that both subsidized loans and - even more impactful - combined with grants increased the growth of revenue and employment, as well as R&D investments. This suggests that overcoming initial financing constraints can enormously impact firm development. Recent research focuses on whether startup subsidies also facilitate follow-on financing by (non-public) investors. Berger and Hottenrott (2021), for instance, study how different types of venture capitalists invest in startups based on whether they received public subsidies or not. They find a positive relationship between subsidies and follow-on venture capital (VC) funding. VC investors, however, typically cluster in more accessible locations (near airports, for instance) to have better access to potential investment targets (Lutz et al., 2013; Woo, 2020). Previous research also stressed the role of knowledge spillovers in hubs (Bikard and Marx, 2020) and R&D alliances leading to a higher innovation performance depending on whether such activities are feasible (Hottenrott and Lopes-Bento, 2015). For instance, Agrawal et al. (2017) focus on the role of knowledge flows between and within regions through more mobility and goods flow. Looking at historic highway plans, they find that the building of roads caused an increase in the number of patents and more patent citations. Besides closeness to investors and networks, the location of a startup may also affect its access to non-financial resources such as human capital. Studies by Asher and Novosad (2020) and Gertler et al. (2022) highlight the vital role of transport infrastructure in achieving accessibility and eventual economic development of regions. Moreover, Zheng et al. (2022) stress the importance of going beyond the analysis of roads by showing the significant impacts of high-speed rail infrastructure on entrepreneurial activity.

Based on these insights, this study aims to extend research on agglomeration economies or the flow of human capital in cities (Black and Henderson, 1999; Glaeser and Gottlieb, 2009) by explicitly measuring accessibility using a portfolio of transport modes (including roads as well as public transport) and by focusing on new firms. The need for going beyond the urban/rural dichotomy is also stressed in the findings by Fritsch and Wyrwich (2021b). In their study, they find that patenting activity in selected OECD countries does not decrease with a less urbanized environment. This only happened in more centrally structured countries, like South Korea and the United States, whereas the effect disappeared in countries like Germany. They conclude that the role of big cities as innovation hubs might be overemphasized. Therefore, the question that is of interest in this study is how public subsidies are best placed to support startups most efficiently.

To study the effects of subsidized loans and grants on knowledge-intensive startups' growth and R&D expenditures, we replicate the study of Hottenrott and Richstein (2020) using data that also cover more recent years. As mentioned before, the initial paper showed that - on average - financial startup support is indeed effective in facilitating additional innovation activities and investments. We expand the analysis in this paper by further differentiating between the locations of the subsidy recipients and by testing whether the extent to which subsidies result in higher investments and performance (i.e., the treatment effect) depends on the transport accessibility of the location.

Based on insights from previous research, we set up two opposing hypotheses. The first is based on the idea that startups in less accessible places have a higher need for support *(Need-Hypothesis)* because their location provides less infrastructure and fewer spillovers. Public support may therefore be more effective since the constraint is more binding, and hence there is more potential to be uncovered. Moreover, better accessibility may come at the cost of higher competition for resources and therefore higher costs, including for renting and wages (Gertler et al., 2022), which may make expansion of business activities in response to subsidies less costly and more feasible in less accessible locations. This implies that:

Hypothesis 1: *Treatment effects of startup subsidies are larger in less accessible locations (Need).*

On the other hand, startups may be able to make more effective use of subsidies in better accessible locations because they provide complementary infrastructure and resources. Moreover, there may be better opportunities in more accessible places with regard to collaboration and exchange with other organizations. Perhaps most importantly, better accessibility, as we define it in this study, means better access to people *(Opportunity-Hypothesis)*. People are important as customers, i.e., they may reflect local demand as well as constitute potential employees. While not everyone is of the same relevance to new firms, access to individuals with matching skills may matter a lot. Since young firms find it particularly difficult to hire their first employees as they compete with established firms and have limited financial resources (Roach and Sauermann, 2023), they may need to locate in places where there is a sufficiently large pool of potential hires or where wages are lower. Especially, R&D intensive startups have high human capital requirements, and access to potential employees with the necessary R&D skills may be crucial for their business to succeed. Therefore being in a better accessible location could increase the returns to (R&D) investment and hence lead to a better cost-effectiveness of public startup support. We, therefore, hypothesize that:

Hypothesis 2: *Treatment effects of startup subsidies are higher in better accessible locations (Opportunity).*

To answer the research question of whether local accessibility matters for the effectiveness of startup subsidies, it seems crucial to differentiate between the population attraction factor that defines accessibility. Using the general population as attraction is plausible following the market-access argument (Chen and Wang, 2022; Donaldson and Hornbeck, 2016). However, following the human capital idea, we may need to differentiate between more and less relevant populations, with more relevant being people who may help the startup's performance, for instance, in knowledge-intensive tasks and areas that matter for the development and market introduction of novel products and services.

4.4 Estimation Methods and Data

In order to calculate whether accessibility impacts the effectiveness of subsidies for startups, we first estimate whether public financial support generally makes a difference for young companies. We create two groups of startups, one that received some form of subsidy and one that did not. By doing this, we replicate Hottenrott and Richstein (2020) with five more years of data and conduct a nearest neighbor propensity score matching with a caliper. Then we combine it with elements of exact matching, e.g., Huber et al. (2013). After having estimated the average treatment effects on different outcomes, we can analyze whether the individual firm's treatment effect depends on the accessibility of its location.

4.4.1 Method

In a first step, we estimate the treatment effect of subsidies on a set of outcome variables for subsidized versus non-subsidized new firms. We first predict whether a startup will be subsidized by any kind of funding instrument given the predictor (control) variables during the observation period. We collect the following variables that predict the treatment: Founder(s)' age, academic background, industry experience, entrepreneurial experience, prior negative entrepreneurial experience, founding motive, team (composition, e.g., gender), current number of employees, revenue, profit, other financing sources, patents, R&D activity, market penetration (e.g., export), capacity utilization. We conduct t-tests to detect differences between the variable means before (see Table 4.1) and after (see Table 4.5) the matching process. Before the matching, we expect subsidized and non-subsidized startups to differ in both control and outcome variables. After the matching, provided that the matching is indeed successful, we would not expect differences in firm and founder characteristics on which the matching was based. The remaining differences in the outcome variables can then be attributed to the treatment. Our main outcome variables are R&D expenditure, R&D personnel, tangible investments, product innovation, number of employees, revenues, and exit. The average treatment effect can be described as follows:

$$\alpha^{TT} = \frac{1}{N^T}\sum_{i=1}^{N}(Y_i^T - \widehat{Y}_i^C) \tag{4.4.1}$$

where Y_i^T is the outcome of a firm in the treatment group, and vice versa, $\widehat{Y}_i^C$ is the outcome when the treatment group would not have been treated. Since the counterfactual situation is not directly observable, the $\widehat{Y}_i^C$ needs to be estimated. It is, therefore, crucial to model the selection stage carefully. Public funders select startups based on specific observable criteria. They could either favor underperforming companies (backing losers) that need the support to enhance their business or overperforming firms (picking winners) that are more likely to prevail (Cantner and Kösters, 2012). The firms also self-select into funding programs when applying for a subsidy. Both mechanisms lead to a selection bias in the subsidized versus unsubsidized groups, and without making both groups comparable through matching, we may incorrectly attribute differences in firm performance to the treatment (Imbens and Wooldridge, 2009).[2] To come close to an experimental setup, we employ several control variables (Set X) to reduce selection bias (Lechner and Wunsch, 2013). Our survey data provides extensive firm and founder characteristics, making the matching quite comprehensive. Building on Rubin (1977) and their conditional independence assumption (CIA), we use the counterfactual group with the same criteria of X to estimate any outcome Y. $S = 1$ being the subsidized startups and $S = 0$ being the unsubsidized ones as $S \in \{0, 1\}$. If the CIA hold, we can claim that $E(Y \mid S = 1, X) = E(Y \mid S = 0, X)$ and hence any observable differences in Y must be explained by the treatment.

We estimate the propensity score used in the matching approach from a probit regression for the probability of a subsidy receipt conditional on the criteria X. This leaves us with one propensity score containing all the criteria information. Following Hottenrott and Richstein

[2]Besides matching, there are other methods of estimating a counterfactual situation and hence treatment effects, such as difference-in-differences estimation. However, due to missing pre-treatment data for most of the startups, this is not a suitable option in our case since most startups receive public funding in their first or second year of operations.

(2020), we then use a nearest-neighbor matching method to ensure that we match firms with the most similar characteristics and a highly similar probability of receiving a subsidy. Additionally, a caliper is used to avoid matching firms which exceed a maximum distance between propensity scores. Moreover, we combine this with exact matching within the same technology sector and within the geographical location in former East or West Germany. That is, we only select within these strict bins. Following the matching, we compute the average treatment effect on each Y outcome as:

$$\alpha^{TT} = E(Y^{T}|S = 1, X = x) - E(Y^{C}|S = 0, X = x) \tag{4.4.2}$$

After the propensity score matching, we can estimate whether the accessibility impacts the treatment effect on subsidized companies in terms of their outcomes in the following period: R&D expenditure and employees, tangible investment, product innovation, employees, revenue, and the probability of exit (outcomes O). We use the logged version and ratios of R&D expenditures, employment, revenue, as well as tangible assets and investment to reduce the impact of skewed distributions in some of the variables on the mean values. In this analysis, we distinguish between different attraction factors in the accessibility calculation, such as the general population, potential employees, potential *research* employees, and how competitive the labor market is. As we will describe in the following in more detail, we use an accessibility index that captures several modes of transport, which facilitates comparisons across cities, more peripheral, or rural areas. A detailed description of the utilized data follows in the next section. In particular, we estimate linear models such that:

$$\alpha_i^{TT}(O) = Y_i^{T} - Y_i^{C} \tag{4.4.3}$$

Higher values in the respective outcome $\alpha_i^{TT}(O)$ indicate that a firm benefited from a larger individual treatment effect as measured in the distance of the firm's achieved outcomes as compared to its matched twin firm. Since we match based on many firm and founder characteristics, industry dummies or other controls turn out insignificant in these models.

4.4.2 Data

Our data set stems from two main sources of information. The first is the IAB/ZEW Startup Panel, from which we obtain founder and firm information as well as the subsidy status of a company. The second main data source is the company locations' accessibility scores which we derive from a multi-mode short- and long-distance transport choice model.

4.4.2.1 Startup Panel

The first main data set is retrieved from the IAB/ZEW Startup Panel, which contains the economic characteristics of young companies and their founders in Germany. It is constructed as an annual computer-aided telephone survey based on a stratified random sample of newly registered businesses. The collected responses amount to around 5000-6000 startups per wave. The firms in the panel are at maximum seven years old, and for the first interview, the age limit is three years. Spin-offs (or demergers) and subsidiaries of other companies are excluded since they do not constitute new independent ventures. A detailed description of the panel can be found in Fryges et al. (2009). We categorize firms into 11 sectors: cutting technology manufacturing (8.3%), high-technology manufacturing (6.5%), or technology-intensive services (18.4%), software (6.8%), low-technology manufacturing (13.4%), scientific services (5.9%), other company services (5.9%), creative services (3.7%), other customer services (7.7%), construction (11.8%), and retail (11.6%). The average founder age is 45 years, and 13.3% have at least one female founder. About 86% of startups are located in western Germany. About 39% of startups are founded by teams implying that the majority of startups are founded by one person only. The final data set consists of 10,435 firms that were founded between 2005 and 2018 and were observed up to eight times during this time period.

4.4.2.2 Treatment Variable

We consider a startup to be subsidized if it received either a grant (e.g., cash payment to founders or wage substitute) or a preferential, publicly-backed loan. This consideration includes programs like the *EXIST* program or startup bank loans from the KfW Banking Group. Regional banks also offer support through loans that do not require collateral or have other favorable conditions, such as low-interest rates or repayment-free years.[3]

4.4.2.3 Outcome Variables

We focus on relevant outcome variables that describe or determine a startup's success. Regarding innovation efforts, these are *R&D expenditures*, the number of *employees*, the ratio of R&D expenditures per employee, and the share of R&D employment among the total employees. These variables can be termed input oriented. These measures are also used in other studies on the effect of startup subsidies (Colombo et al., 2013a; Czarnitzki and Lopes-

[3]See Hottenrott and Richstein (2020) for a more detailed discussion of differences between grants and loans and Zhao and Ziedonis (2020) for a study focusing on subsidized loans.

Bento, 2013). Following Hottenrott and Richstein (2020), we also consider investments in tangible assets (*tangible investment*). To capture the innovation output of a company, we use the binary variable *product innovation*, which covers products that are new to the market and were introduced in the years after the subsidy (up to three years). We also analyze the revenue of a startup, as well as whether it quit business activities in the years following the subsidy receipt; this can be a (voluntary) liquidation or because of insolvency. We obtain this indicator from Creditreform, Germany's largest credit rating agency.

To account for the skewness of the distribution in the monetary variables, we apply the logarithm and add one unit in the case of zero values[4].

4.4.2.4 Matching Variables

To replicate previous studies as closely as possible, we primarily rely on the same variables and method as Hottenrott and Richstein (2020) to find a suitable control group. As shown in literature (Chandler and Hanks, 1994; Mitchelmore and Rowley, 2010), it is important for public funders to selectively distribute startup subsidies in order to achieve the best value for taxpayers' money. Consequently, the allocation of subsidies to startups is not random, i.e., founder and firm characteristics significantly explain whether or not a company received public financial support. Startups by older founders, for instance, are less likely to be financially supported, while those founded by a team are more likely. The higher the innovation orientation, as measured by R&D expenditures, the more likely it is that a firm received a subsidy. To reduce omitted variable bias and selection bias, we employ a set of control variables that are firm-related and founder-related on which the allocation is likely based. More precisely, the variables include indicators that may explain a startup's subsidy receipt as well as firm performance. These are the founders' human capital measured by formal education of the founder(s) (*university degree*), *vocational training*, or *Master craftsperson* title, the highest non-academic rank in Germany). Moreover, industry experience is captured as the number of years of the most experienced founder. As some research shows, having founded a company before might be preferred by subsidy providers to novice founders due to their potential lack of managing knowledge or a business network (Wright et al., 1997). Therefore, it counts as entrepreneurial experience if at least one founder has founded before. To capture life experience more generally, the oldest founders' age is included, and startups are also distributed into team founders and solopreneurs. Although gender should not influ-

[4]See Table A.3.2 for pairwise correlations between the outcome variables.

ence the success probability of a startup, recent research shows that the amount of funding given to a young firm is influenced by founder gender (Lins and Lutz, 2016). Therefore, we include an indicator for whether the start has at least one female founder. For the startup characteristics, we employ the age of the firm, as younger firms empirically are more prone to financial constraints and rely more on funding than more established startups. Young firms are also seen as more interested in pursuing innovation (Czarnitzki and Lopes-Bento, 2013). Additionally, the number of patents that the firm has already produced is included. Since there are still some structural differences between former East and West Germany, we also only match firms strictly only within these broad regions as well as only within sectors[5]. We examine whether there are any significant differences between the groups in these characteristics using *t*-tests before and after matching. Table 4.1 shows t-tests of differences in variable means before matching. As expected, subsidized and non-subsidized firms differ quite substantially in most characteristics, and the group of startups without support is substantially larger than the group of subsidy recipients.

4.4.2.5 Accessibility

The accessibility of a region is a score indicating how accessible a region is for a specific group of people. This answers the question of how many people of the general population, employees (i.e., individuals of working age), or research employees can travel from one zone to another zone using different transport modes in a given amount of time. The agent-based short and long-distance model follows an approach that consists of trip generation, destination choice, time of day choice, mode choice, and trip assignment (Moeckel et al., 2020; Pukhova et al., 2021). The accessibilities are therefore calculated as follows:

$$Accessibility_i = \sum_{j=1}^{n} D^{j^{\alpha}} * e^{-\beta * tt_{ij}} \tag{4.4.4}$$

where D describes the number of opportunities at destination zone j or the *attraction factor*, tt_{ij}, describes the travel time between zones i and j, α is a weight variable affecting the attractor, β is a time-sensitivity parameter, meaning that higher β values lead to longer travel times being sanctioned. Figure 2.2 in Chapter 2 illustrates the model in more detail.

For the purpose of generating accessibility values for each zone using this model, Germany is divided into 11,717 transport analysis zones that essentially match German municipalities,

[5]See Table A.3.1 in the Appendix for details on the distribution of observations across industries and by subsidy status. See Table A.3.4 for pairwise correlations between the matching variables.

Table 4.1: Comparison of Control Variables Before Matching

	Non-recipients N = 43891		**Recipients** N = 8017		
	Mean	SD	Mean	SD	*t-test*
Founder characteristics					
University education	.281	.002	.270	.005	.049
Vocational training	.287	.002	.275	.005	.030
Master craftsperson	.229	.002	.276	.005	.000
(Founder) Age	44.855	.051	43.329	.109	.000
Industry experience	16.748	.049	15.795	.104	.000
Entre. experience	.416	.002	.355	.005	.000
Failure experience	.065	.001	.065	.003	.925
Opportunity-driven	.751	.002	0.755	.004	.001
Female founder	.181	.002	.187	.004	.211
Startup characteristics					
Team	.307	.002	.336	.005	.000
Startup age$_{t-1}$	2.986	.009	2.453	.018	.000
Limited liability	.480	.002	.479	.006	.782
ln(Tangible Assets)	5.558	.021	5.315	.051	.000
Patent(s)	.099	.011	.073	.010	.350
Export activity$_{t-1}$	.157	.002	.180	.004	.000
Capacity utilization$_{t+1}$	82.831	.120	84.992	.269	.000
East Germany	.125	.002	.188	.004	.000
ln(R&D-Expenditure)$_{t-1}$	1.346	.017	1.821	.045	.000
ln(Employees)$_{t-1}$	.880	.004	.824	.011	.000
ln(Revenue)$_{t-1}$	7.471	.028	6.254	.068	.000
ln(Tangible Investment)$_{t-1}$	4.957	.023	4.995	.057	.518
Profit$_{t-1}$	.065	.001	.065	.003	.925

with the exception of the 14 largest cities, which are additionally divided into smaller units at the borough level. Cross-border accessibility is also accounted for, as all neighboring country zones are included in the calculation. A transport network consisting of roads, railroads, and local public transport ways, such as sub-urban rails, is used to estimate travel times[6]. Short distances are under 40km long, as long-distance trips are over 40km. Note that local public transport modes are used to access long-distance modes, such as taking the bus to the closest train station. For our model, an agent chooses a route and a mode of transport to get from zone A to a chosen zone B. The calculation is based on actual travel behavior captured by the Mobility in Germany survey, a nationwide travel survey by the Ministry of Transport and Digital Infrastructure (Federal Ministry of Transport and Digital Infrastructure, 2017). This survey is conducted every five to nine years since 1970, and we use the 2017 survey data for the simulation. The survey includes socio-demographic

[6]Information on the road and rail network and public transport schedules and is retrieved from the following sources: OpenStreetMaps (https://www.openstreetmap.org) and GTFS (https://gtfs.de). Retrieved on 13.03.23.

information about the interviewees within different groups and regions, as well as information on the trips a person took. This information is then used to simulate a synthetic population. A matrix system between every zone in Germany is employed to calculate the accessibility for every zone using the gathered information from the mobility survey and the synthetic population as well as information on the transport network (Pukhova et al., 2021). This provides us the information about the freeflow travel times between all zones. To include congested traffic in the analysis, the Multi-Agent Transport Simulation (MATSim) by Horni et al. (2016) is used. In this study, we call the different groups of population attractors. This leaves us with an accessibility score for access to the general population, potential employees, potential research employees, or employees when considering the location's competitiveness. The competitive accessibility is lower when there is a high number of potential employees, which might increase the competition between local firms for employees. All accessibilities are considered to be relatively stable over time, which might be a plausible assumption in the German context with long building times. Table 4.2 illustrates descriptive statistics for the resulting standardized accessibility scores for the different modes of transport and by accessibility destination (attractor) type (general population, employees, research employees) and for competitive employment. As can be seen from these values, the different accessibility modes are highly correlated.

Table 4.2: Descriptive Statistics of Accessibilities

Accessibility Attractor	Transport Mode	Mean	Std. Dev.	Min	Max
Population	Car (congested)	0.394	0.148	0	1
	Bus, metro, tram	0.081	0.089	0	1
	Long-distance rail	0.142	0.123	0	1
	Long-distance bus	0.067	0.089	0	1
Employees	Car (congested)	0.401	0.151	0	1
	Bus, metro, tram	0.0799	0.097	0	1
	Long-distance rail	0.155	0.134	0	1
	Long-distance bus	0.070	0.097	0	1
Research Employees	Car (congested)	0.466	0.181	0	1
	Bus, metro, tram	0.047	0.078	0	1
	Long-distance rail	0.164	0.150	0	1
	Long-distance bus	0.047	0.085	0	1
Competitive Employment	Car (congested)	0.377	0.092	0	1
	Bus, metro, tram	0.309	0.129	0	1
	Long-distance rail	0.194	0.123	0	1
	Long-distance bus	0.179	0.088	0	1

Notes: Observations = 11,717 (at zone level).

In Figure 4.1, the congested-car accessibility for the general population is mapped in comparison to the competitive employment accessibility distribution across Germany. For informational purposes, the ten largest cities of Germany are marked in Map 4.1a. Compared to the accessibility for the general population, which is higher in mid-west Germany, the competitive employment accessibility is higher is more balanced among the cities. In Figure 4.2, the four transport modes are mapped for the competitive employment accessibility. For the car accessibility, highway routes across Germany are distinguishable with higher accessibility; the public transport modes also correspond to smaller cities in between larger cities.

In order to account for the correlations between the accessibility scores by transport mode[7], we construct indices for each destination type that takes into account various forms of transportation. Table 4.3 shows the results from a confirmatory principal component analysis that shows that the four accessibility scores per destination type map with high factor loading into a single component. This means we can use the predicted factor scores per group as an accessibility index capturing all four transport modes in the following.

Table 4.3: Factor Analysis for the Different Types of Accessibilities

Accessibility Attractor	**Mobility Mode** at $\alpha = 1.0$ and β=1.0	**Factor loadings** (Factor 1)
Population	Car (congested)	0.629
	Bus, metro, tram	0.914
	Long distance rail	0.865
	Long distance bus	0.862
Employees	Car (congested)	0.611
	Bus, metro, tram	0.920
	Long distance rail	0.868
	Long distance bus	0.879
Research employees	Car (congested)	0.650
	Bus, metro, tram	0.903
	Long distance rail	0.878
	Long distance bus	0.897
Competitive employees	Car (congested)	0.722
	Bus, metro, tram	0.779
	Long distance rail	0.799
	Long distance bus	0.734

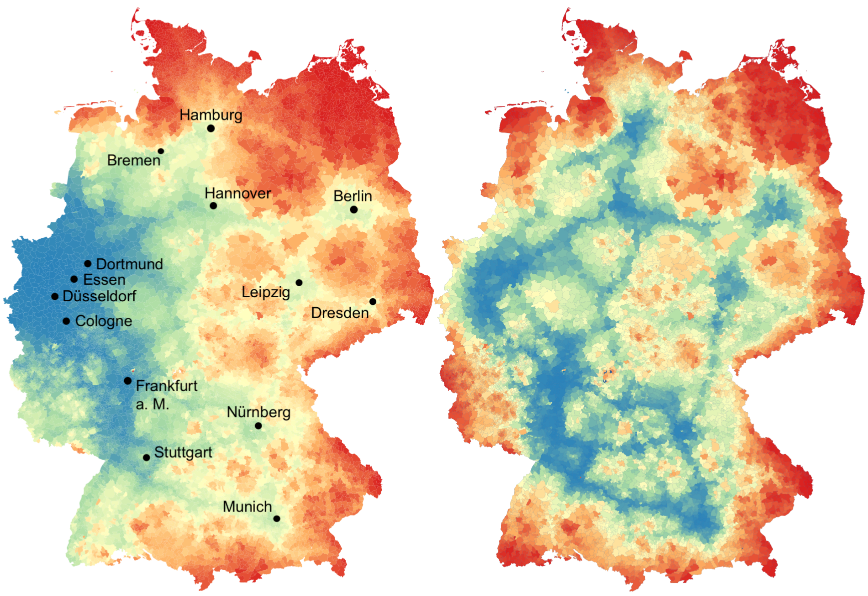
4.5 Estimation Results

In this section, we first describe the results of the analysis of how subsidies are distributed to startups to build up our matching sample before we discuss the treatment effects estimation

[7]See Table A.3.3 in the Appendix.

Figure 4.1: Congested Car Accessibility for the Different Populations

(a) General population **(b)** Competitive employment



Congested car accessibility with the general population (left) and competitive employment (right) as the attraction factor ($\alpha = 1.0$, $\beta = 1.0$). Scaling color gradient: Blue = high accessibility (1); yellow = medium accessibility; red = low accessibility (0).

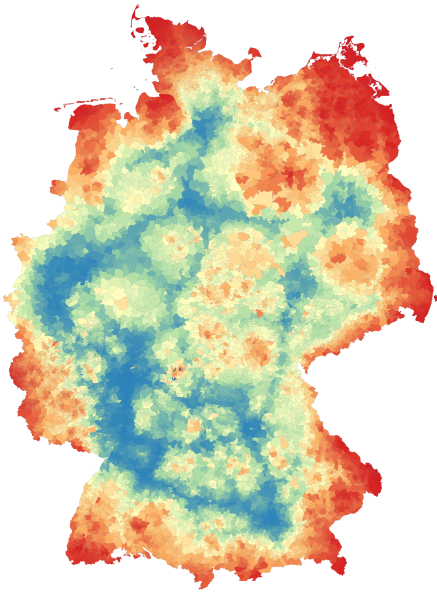
results and the heterogeneity analysis. Table 4.4 shows the results of the probit estimation for obtaining the propensity score which we use in the sample balancing with some elements of exact matching. The model predicts about 89% of the observations correctly, indicating a good model fit. We obtain a quite balanced sample using the propensity scores from this model combined with elements of exact matching for identifying the most similar non-subsidized startup for each treated one. Table 4.5 shows the t-tests after matching with sample means no longer showing significant differences between groups.

Figures 4.3a and 4.3b graphically illustrate the distribution of the propensity score by groups before and after matching. While the curves differ before matching, they almost perfectly overlap after matching. Figure 4.4 further illustrates that after matching, we obtain quite a comparable regional distribution of recipients and non-recipients across Germany, representing sufficient variation in terms of startup location and accessibility.

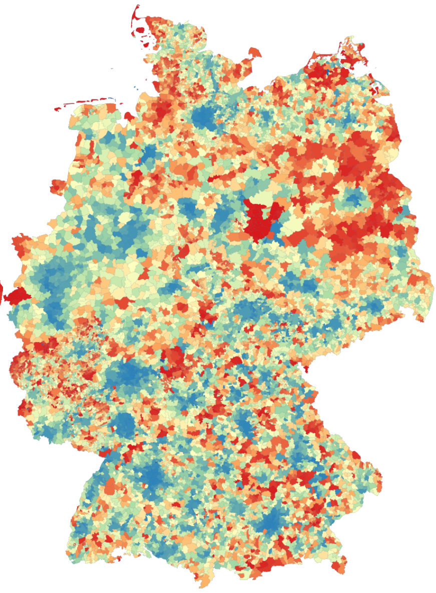
Table 4.6 shows the differences in the outcome variables after matching. Given that the observable firm and founder characteristics - on average - no longer differ in the matched sample, we can interpret these differences in means in the outcomes as treatment effects. In line with previous findings, these results confirm that there are positive average treatment

Figure 4.2: Accessibility with Competitive Employment as the Attraction Factor

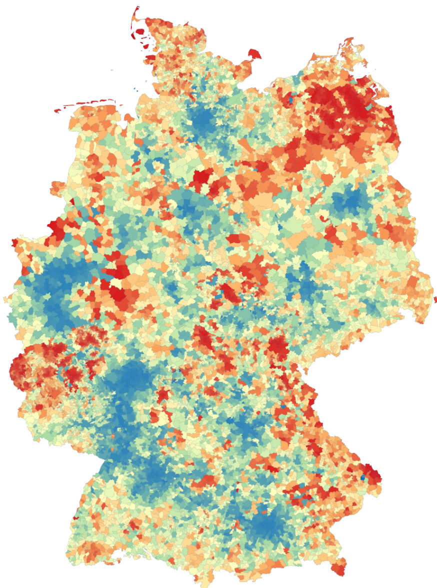
(a) Car Cong.



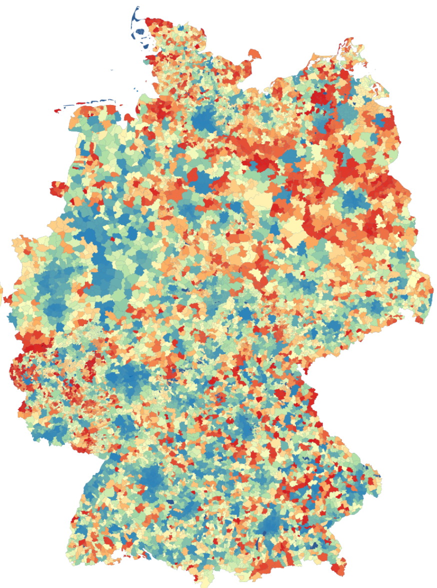
(b) Local BMT



(c) LD Rail



(d) LD Bus



Accessibility within Germany with competitive employment as the attraction factor ($\alpha = 1.0$, $\beta = 1.0$). Scaling color gradient: Blue = high accessibility (1); yellow = medium accessibility; red = low accessibility (0).

effects on R&D activities and innovation as well as on investments and firm growth as indicated by revenues and the number of employees. The likelihood of firm exit through liquidation or bankruptcy is significantly lower in the group of startups that received some form of public financial support, on average.

After the matching and establishing that the treatment effects are, on average, statis-

Table 4.4: Probit Estimations Before Matching

Variables	Coefficient	$P > \|z\|$
Founder(s) characteristics		
University	0.001	0.962
Vocational training	-0.052	0.024
Master craftsperson	0.003	0.903
(Founder) Age	-0.003	0.020
Industry experience	-0.002	0.068
Entrepreneurial experience	-0.178	0.000
Failure experience	0.110	0.005
Opportunity-driven	-0.042	0.049
Gender diversity	-0.009	0.728
Startup characteristics		
Team	0.079	0.000
Startup age	-0.124	0.000
Limited liability	0.013	0.557
ln(Tangible Assets)	0.001	0.955
Patent(s)	-0.004	0.522
Export activity$_{t-1}$	0.153	0.000
Capacity utilization$_{t-1}$	0.003	0.000
East/west	0.451	0.000
ln(R&D-Expenditure)$_{t-1}$	0.038	0.000
ln(Employees)$_{t-1}$	0.170	0.000
ln(Revenue)$_{t-1}$	-0.024	0.000
ln(Tangible Investment)$_{t-1}$	0.003	0.144
Profit$_{t-1}$	0.000	0.002
Observations	10262	

Notes: Chi^2(3) = 85.94, $Prob > chi2$ = 0.001; Correctly classified = 88.65%. Two-sided t-test mean differences between subsidized and non-subsidized startups (p-values). Period *t-1* marks the year prior to a subsidy receipt in year *t*. Variables without a time subscript are either based on the founding year or time-invariant. The model contains industry and year-fixed effects.

tically significant, we estimated whether the accessibility has an impact on the size of the estimated treatment effect on subsidized companies. We consider the same outcome variables as in the estimation of the average treatment effects, i.e., R&D expenditure and employees, tangible investment, product innovation, employees, revenues, and the probability of exiting. In terms of different accessibilities, we distinguish between the general population, potential employees, potential research employees, and competitive employment as the attraction factor in the accessibility calculation. The main results are presented in Table 4.7.

The results indicate that there are significant positive effects of the general population accessibility on the treatment effect on the logged number of R&D employees (β = 0.032). This is also the case for the accessibility to employees (β = 0.045) and particularly to research employees (β = 0.080) in a region. The effect is thus most pronounced when we

Table 4.5: Comparison of Control Variables After Matching

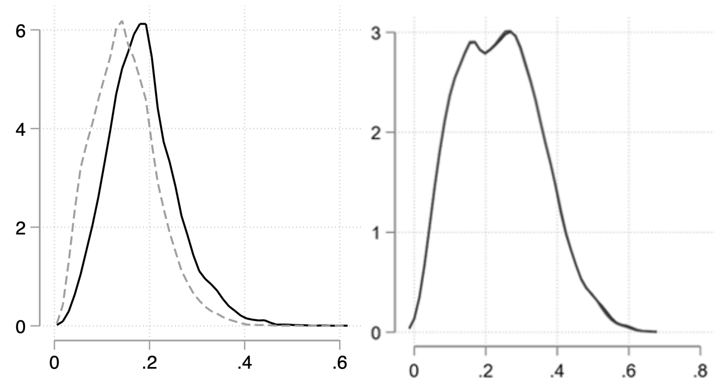
	Non-recipients		**Recipients**		
	Mean	SD	Mean	SD	*t-test*
Founder characteristics					
University education	.273	.005	.269	.005	.593
Vocational training	.271	.005	.276	.005	.445
Master craftsperson	.273	.005	.276	.005	.619
(Founder) Age	43.301	.119	43.343	.109	.795
Industry experience	15.709	.112	15.809	.105	.515
Entre. experience	.364	.005	.355	.005	.255
Failure experience	.071	.08	.065	.003	.186
Opportunity-driven	.766	.005	0.767	.005	.970
Female founder	.183	.004	.187	.004	.528
Startup characteristics					
Team	.336	.005	.334	.005	.814
Startup age$_{t+1}$	2.483	.017	2.453	.018	.240
Limited liability	.489	.006	.477	.006	.154
ln(Tangible Assets)	5.237	.051	5,326	.051	.220
Patent(s)	.058	.007	.072	.010	.213
Export activity$_{t+1}$	.178	.004	.178	.004	.901
Capacity utilization$_{t+1}$	85.340	.301	84.875	.269	.249
East Germany	.185	.004	.185	.004	1.0
ln(R&D-Expenditure)$_{t+1}$	1.796	.044	1.784	.045	.857
ln(Employees)$_{t+1}$	.829	.009	.819	.011	.475
ln(Revenue)$_{t+1}$	6.303	.067	6.254	.068	.611
ln(Tangible Investment)$_{t+1}$	4.916	.056	4.98	.058	.420
Profit$_{t+1}$	7.439	.065	7.315	.066	.185

Observations: 7977 each group, except for variable *Profit*: non-recipients $n = 5189$; recipients: $n = 5073$.

Figure 4.3: Estimated Propensity Score Before and After Matching

(a) Before matching: Treatment group and potential control group (dotted line).

(b) After matching: Treatment group and selected control group.



Estimated propensity score of the treatment group and selected control group before and after matching.

consider potential R&D workers. This shows that subsidies are most effective in terms of hiring additional R&D employees in startups when such human capital is actually available

Figure 4.4: Spacial Distribution Across Zones of the Treatment Group and Selected Control Group After Matching.

(a) Subsidy non-recipients **(b)** Subsidy recipients

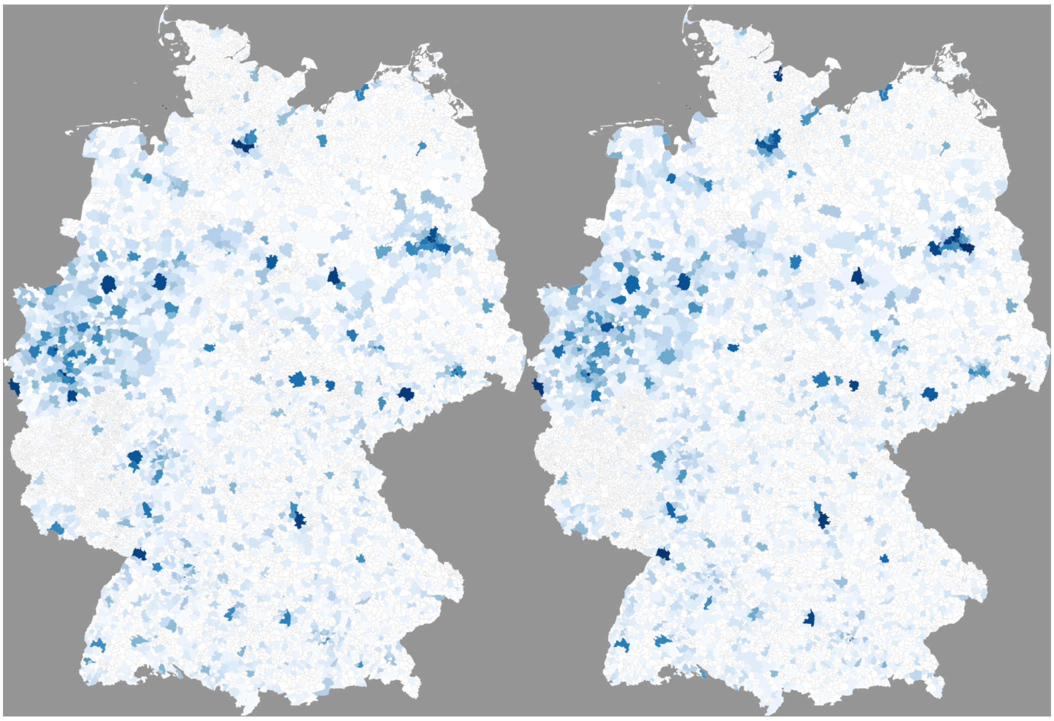


Table 4.6: Outcome Variables After Matching

	Non-recipients			**Recipients**			
Variables	N	Mean	SD	N	Mean	SD	t-test
$\ln(\text{R\&D-Expenditure})_{t+1}$	6748	1,738	.047	6714	1,983	.051	.001
$\ln(\text{R\&D-Personnel})_{t+1}$	6853	.248	.011	6812	.379	.016	.000
$\ln(\text{Tangible Investment})_{t+1}$	7530	3,772	.055	7491	4,370	.057	.000
Product innovation$_{t+n}$	7977	.286	.005	7977	.318	.005	.000
$\ln(\text{Employees})_{t+1}$	6797	.926	.011	6774	1,096	.012	.000
$\ln(\text{Revenue})_{t+1}$	6834	6,928	.074	6838	7,735	.074	.000
Exit$_{t+n}$	7977	.278	.005	7977	.253	.005	.001

and accessible. When considering the competition for employees, the effect is even stronger ($\beta = 0.128$), stressing the importance of access to potential hires. On R&D expenditure, the accessibility for research employees has a positive and significant effect ($\beta = 0.122$), as well as the accessibility for competition on employment ($\beta = 0.213$). One can see a slightly positive trend for competitive accessibility on product innovation ($\beta = 0.013$). When looking at R&D expenditures, we find that while access to the general population does not have any impact, access to researchers explains the magnitude of the treatment effect, supporting our previous conclusions that the availability of adequate human capital increases the effectiveness of public startup subsidies.

Table 4.7: Results for the Impact of Accessibility on Subsidy Effectiveness

	Accessibility			
Outcome variables	General Population	Employee Population	Research employees	Competitive employment
$\ln(\text{R\&D Expenditure})_{t+1}$	0.028 (0.033)	0.048 (0.035)	0.122** (0.037)	0.213*** (0.055)
$\ln(\text{R\&D Employment})_{t+1}$	0.032*** (0.010)	0.045*** (0.011)	0.080*** (0.016)	0.128*** (0.022)
$\ln(\text{Tang. Investments})_{t+1}$	-0.001 (0.042)	0.005 (0.044)	0.023 (0.043)	0.041 (0.069)
Innovation_{t+n}	0.003 (0.004)	0.004 0.004	0.005 (0.004)	0.013* (0.007)
$\ln(\text{Employees})_{t+1}$	0.008 (0.008)	0.011 (0.009)	0.014 (0.009)	0.028* (0.014)
$\ln(\text{Revenue})_{t+1}$	0.033 (0.054)	0.053 (0.056)	0.061 (0.055)	0.103 (0.087)
Exit_{t+n}	-0.001 (0.004)	-0.002 (0.004)	-0.007 (0.004)	-0.003 (0.007)

Notes: N = 5692, * p<0.05, ** p<0.01, *** p<0.001. OLS regressions used to calculate coefficients. Standard errors are clustered by zone identifier.

Thus, being located in a better accessible location in terms of research employees leads to higher additional spending on R&D through the subsidy. This supports our first hypothesis (opportunity), stating that the treatment effect of startup subsidies is higher in better accessible locations for R&D externalities due to human capital suited to the needs of young companies. We find no evidence for the treatment effects in terms of tangible investments to be more extensive for firms in better accessible places. Similarly, we cannot conclude that revenue or business failure (exit) effects of subsidies vary depending on the accessibility of the location. In terms of innovation and overall employee growth, we find some (weak) indication that the better accessible the location in terms of competitive accessibility, the larger the subsidy's effect on the total number of employees and the likelihood of innovating. The latter results may be due to the short-term perspective of our outcome variables. In other words, the presented results show that local accessibilities matter particularly for the magnitude of input additionality and provide support for the *Opportunity Hypothesis*.

4.6 Discussion and Conclusion

In this study, we investigated whether the location of a startup impacts the effectiveness of startup subsidies. We hypothesized that the local accessibility of a startup's location could affect the use that it can make from the provision of financial support. On the one hand, startup subsidies given to new firms in better accessible regions could make more of a difference because of the opportunities that the firms have in such locations. Thus, the money falls on more fruitful grounds. On the other hand, it could be argued that firms in less accessible locations have a need for additional resources to help them compensate for the weaknesses of the location in terms of accessibility. Based on very detailed, regionally fine-grained information on local accessibility, we constructed scores capturing a location's access to potential employees taking into account various modes of transportation. The calculation of the accessibilities was based on an agent-based model taking into account congestion and actual travel times between more than 11,717 zones within Germany. We further made use of detailed data on newly founded companies which allowed us to re-estimate the treatment effect models of Hottenrott and Richstein (2020). We thereby built on previous research that documented positive *average* treatment effects for startup subsidy programs (Almus, 2004; Colombo et al., 2013b; Howell, 2017; Hottenrott and Richstein, 2020; Grilli et al., 2017).

Going beyond the estimation of the average treatment effects, we estimated individual treatment impacts showing that they vary substantially around the mean. Our main results show that local accessibility, especially for research employees, positively and significantly affects the magnitude of the individual treatment effects. Thus, the subsidy is more effective when there are universities and research institutions in the area providing highly skilled knowledge workers. Conclusively, the accessibility to research employees seems to have the biggest impact on the effectiveness of startup support when we consider additional innovation activities as the relevant outcome.

This finding could be explained by the role of access to human capital in enabling firms to expand their R&D activities in response to additional financial resources. However, for treatment effects on tangible investment, local accessibility does not appear to be relevant. This suggests that the location's importance depends on the subsidy program's objective. If the funding agency aims to promote R&D and innovation, it may be advisable to select firms in locations with better access to qualified employees. For other outcomes, the accessibility of the location does not significantly affect the magnitude of the individual treatment effect. Another long-term implication of this finding is to expand research and training infrastructure, both public and private, to new locations, as it has a direct and indirect impact on new knowledge-intensive companies.

We also find weak evidence for the role of better access to employees for new product development. However, longer-term effects are not considered, and hence, we are careful regarding conclusions related to innovation performance or startup growth.

The results of this study make a valuable contribution to the existing research on the use of startup subsidies as a means of promoting innovation. Our findings indicate that accessibility is critical when it comes to R&D input additionality, but there appear to be no location-based differences for non-R&D inputs, short-term growth, and survival.

This discovery aligns with the previous findings of Rammer et al. (2020), who also did not find strong evidence of regional effects on the effectiveness of government subsidies. Our study contributes to the existing literature by focusing specifically on young firms, which play a crucial role in innovation and regional development (Haltiwanger et al., 2016; Schneider and Veugelers, 2010). As a result, our results have important policy implications. Investing in new firms in regions with better access to highly skilled human capital could increase the return on investment in terms of additional R&D in the area.

In future research, it will be important to consider the possibility of non-stability in regional accessibility. Some locations may experience a lasting impact on local transport infrastructure due to higher startup rates and an increased inflow of established firms. Accessibility could also be endogenous to firm and regional performance, particularly in the long term. It would be interesting to investigate whether accessibility changes over time in regions with high levels of firm entry, such as the impact of new railroad lines like the Munich-Berlin line implemented in 2017 in Germany, which could lead to a different assessment of accessibility and a higher number of long-distance commuters. Examining sector-specific subsidy programs could also yield further insights into this topic. Additionally, differences in the level of digitization in companies could affect our findings, with startups that rely less on in-site work and lack fixed production sites potentially responding differently to the availability of local human capital. The growing trend of remote work could potentially lessen the impact of local accessibility.

5 | Conclusion

5.1 Overview of Main Insights

The topical focus of this dissertation is whether and how transport accessibility impacts local innovation activity (Chapter 2), the location choice of founders (Chapter 3), and the effectiveness of startup subsidies (Chapter 4). To further distinguish between accessibility for different groups of people, I used accessibilities for the general population (Chapter 2), and employees and research employees (Chapter 3 and 4), as well as accounting for competition over employment (Chapter 4). In doing so, I want to shed light on possible implications for entrepreneurs and investors, as well as possibilities to enhance local innovation performance from a policymaker's standpoint. My results suggest that accessibility and mobility play an essential role in innovation activities despite our lives and work merging increasingly with digital technologies. I will describe the results of each chapter in more detail in the following paragraphs and follow up with a conclusion of the overall insights.

The findings in Chapter 2 indicate that transport accessibility significantly impacts local innovation activity. Detailed, regionally fine-grained information on local accessibility was used to capture a location's access to potential employees, customers, and other travelers while taking into account various modes of transportation and probable traffic congestion. The resulting accessibility score for almost each of the 11,717 zones in Germany targets, among others, a location's potential access to human capital, as I use the general population as the primary attractor in this essay. I distinguished between public transport (bus, metro, tram, long-distance rail) and car accessibility (traffic: congested and freeflow). My descriptive analysis reveals substantial differences in accessibility between even close locations and demonstrates that this value captures more than a simple urban/rural dichotomy. The measures underline earlier work that challenged the assumption that innovation predominantly occurs in big cities (Fritsch and Wyrwich, 2021a). In this study, I employed local patenting application data from 2010 until 2014 and a novel innovation score stemming from website texts, called the Predicted Innovator Probability (PIP). The regression results show that better local accessibility is indeed connected to higher patenting activity and more inventive efforts, according to firms' website data. The results based on patent data suggest that this may be related to local accessibility, which can also be relatively high in non-urban areas. The accessibility, however, does not seem to increase innovative activity in accessibilities in the 95th percentile, representing very high accessibility values. Therefore, these extremely high accessibilities do not seem to affect local innovation activity. Accessibility appears to have varying impacts on firms with wide-ranging characteristics, but the differences are minor and warrant further investigation. Different modes of transport also seem to be substitutes for each other, indicating that sufficient accessibility in rural areas can be established by focusing on one mode of transport for the region and developing it in particular. A deeper understanding of this could further strengthen the role of smaller cities with good accessibility for a specific mode of transport. Overall, this study enhances existing research on agglomeration economies and mobility.

In Chapter 3, I was interested in the role of accessibilities on local entrepreneurship behavior. The results presented in this chapter indicate that accessibility also affects young companies, as startup companies are significantly more founded in better accessible areas. I test this using regression analysis on the accessibility for the modes car (congested), long-distance rail, and local bus, metro, and tram. In this chapter, I also factored in different accessibility attraction factors: the general, employee, and research employee population. I then propose a model to determine the relationship between accessibility and startup founding rates in the 11,717 zones in Germany. The startup data stems from the Mannheim Enterprise Panel (Bersch et al., 2014) and covers the period from 2000 until 2019. Results indicate that new firms indeed tend to start out in better accessible regions. This relation is also the case when looking at the accessibility of regions for the general population, employees, and research employees. However, the effect is not detectable in highly accessible regions, much like in the results of Chapter 2.

In this study, I also wanted to learn more about the specific reasons for the specific location choice of startups. Therefore, I also analyzed eleven interviews conducted in 2021 with newly founded German firms on their choice of location. I investigated whether the firms a) made a conscious location choice for their office and production sites and b) whether the accessibility for themselves, potential employees, customers, and transportation of materials impacted that decision. Founders stated that they indeed value accessibility for their firm's location. Accessibility was not the direct factor leading to the decision to start their company; however, factors like a location's mobility and transport connectivity were valued highly. Founders specifically mentioned that the commute time needs to be short and efficient, and founders also expect more employees in regions with better commute time and mobility options. Thus, better accessible areas were expected to offer more skilled personnel. Some startups in the sample also sell products for which they need resource materials and customers that buy products or services. Hence, a location accessible for various individuals and product resources was essential to the founders. Accordingly, most sample startups favored urban environments due to their better accessibility. Factors like cultural offerings, networking with other (young) firms, and better mobility options were critical for the founders to prefer cities. Additionally, startups with a sustainability mission potentially prefer commuting to work by bike or public transport, which is more attainable in urban environments. Reasons for settling outside of cities were that land space for production sites, offices, and living is, on average, less expensive in rural regions and that transportation costs to agricultural sites are minimized.

This dynamic reveals that founders have different preferences regarding location - good accessibility, however, is favored by all founders of the sample in the qualitative study of Chapter 3. The study contributes to the literature on entrepreneurship's location and implies that founders value accessible locations with advanced transport options. It, therefore, builds on existing literature on location factors for young firms (Hellwig, 2023). The insights are valuable to founders and policymakers or subsidy givers in understanding the needs of young firms. Accordingly, this also calls for transport infrastructure improvement in less accessible locations.

In Chapter 4, it is discovered that startups located in areas with better accessibility to research employees tend to have higher additional spending on R&D through subsidies. Investors wanting to support the most promising projects usually focus on firm and founder characteristics (Polonyová et al., 2015; Larsson et al., 2017; Crass et al., 2019). Thus, insights about a startup's specific location accessibility and its impact on the effectiveness of public and private subsidies are still scarce. In the study of Chapter 4, I employed detailed data on startup companies from the ZEW/IAB Startup Panel to re-estimate the treatment effect models of Hottenrott and Richstein (2020) and to measure the accessibility impact on those effects. The study, therefore, builds upon previous research that documented positive treatment effects for startup subsidy programs (Almus, 2004; Colombo et al., 2013b; Howell, 2017; Hottenrott and Richstein, 2020; Grilli et al., 2017). This effect could also be recalculated in this study. For accessibility, I applied all of the transport modes again but used a factor indicator to gather the different transport modes. Apart from looking at the attraction factor of the general population, employees, and research employees, another factor of competition for employment was added in this essay.

The findings support my proposed *Opportunity Hypothesis*, which states that the treatment effect of startup subsidies is higher in better accessible locations for R&D externalities due to human capital suited to the needs of young companies. I found no evidence that the treatment effects concerning tangible investments are larger for companies in better-accessible locations. I can also not conclude that the effects of subsidies on company revenue or business exit (e.g., due to firm failure) are impacted by location accessibility. In terms of innovation and overall employee growth, I find some (weak) indication that the better accessible the location in terms of competitive accessibility, the larger the subsidy's effect on the total number of employees and the likelihood of innovating. The latter results may be due to the short-term perspective of the outcome variables.

In other words, the presented results show that local accessibilities matter particularly for the magnitude of input additionality and support the hypothesis concerning opportunity for the founders. In conclusion, accessibility to research employees appears to have the most significant impact on the effectiveness of startup support when considering additional innovation activities as the relevant outcome. This dynamic suggests that subsidies are more effective when universities and research institutions in the area offer access to highly skilled knowledge workers. In general, the findings could be explained by the role of access to human capital in enabling firms to expand their R&D activities in response to additional financial resources.

It may be, therefore, advisable to select firms located in areas with better access to qualified employees if funding agencies and subsidy givers aim to promote R&D and innovation in young companies. This study significantly contributes to findings about entrepreneurship subsidies and how they are best invested, as well as they have significant implications for both regional development and planning initiatives. Additionally, these findings are relevant to entrepreneurship policy and startup founders, as they emphasize the critical role of geographical location in the growth and success of new ventures.

Concluding from all the insights above, the accessibility of locations does seem to impact *people* in terms of their innovative behavior and entrepreneurship efforts. One remaining question, therefore, is if it comes back to cities performing better because they tend to have a better transport infrastructure and, therefore, are more accessible, and does this mean we need to build bigger cities?

Probably not. As demonstrated in Chapter 2 of this study, even an increase in a single mode of transportation can significantly improve overall accessibility. This action could be especially fruitful in regions with higher improvement potential. It also suggests that more sustainable transportation solutions, such as railroads and mass transit systems, could be implemented in areas with low car accessibility. Such improvements could, in turn, attract knowledge workers, startup founders, investors, and customers to explore rural areas. Tying back to the beginning of this thesis, this would balance the dynamic of *where* innovation and entrepreneurship are brought out best, assuming that people are equally creative and innovative across the globe.

5.2 Outlook for future studies and limitations

According to my studies, innovative and entrepreneurship behavior seems to be influenced by location factors such as a region's transport accessibility. Of course, different aspects might influence this activity that I did not account for in my studies. For example, it should be further investigated whether time-series effects also come into place. Although the local accessibility in Germany is relatively constant over time, an annual reiteration of the accessibility calculation could bring new insights to the current time-invariant analysis. Additionally, path dependencies and the lack of lasting infrastructure shock prevent the identification of causal effects in the presented settings. Looking at cases with a significant increase in transport infrastructure and measuring accessibility pre- and post-treatment would be extremely valuable for insights into the dynamic.

Furthermore, since Germany is an economically decentralized country, comparing this structure to other more centralized countries, like France, or polarized like the United States, would be highly interesting. Many small to medium-sized cities in Germany also perform well in the accessibility measures (see Figure A.0.1). In other, more centrally developed countries like France or South Korea, the effects would potentially be different from my results. For the example of France, which is highly dependent on Paris as the capital, I expect accessibilities to play an even more prominent role in innovation and entrepreneurial performance. Also factoring into this, in developed economies like Germany, transport infrastructure, mobility patterns, and population size are relatively constant in the short to medium term. Studying the role of accessibility in economies with more development potential could be insightful.

In a follow-up study to Chapter 3, more young firms in rural areas could give further insights into why they chose against an urban environment. Overall, this study has provided new insights into the correlation between transport accessibility and where and why startups locate in a specific place, emphasizing that location mobility options still affect entrepreneurial activity even in today's digital world. These insights lack, however, that some observed startups, especially the ones that predominantly work in the software sector, were provided with office space by their startup subsidy program or worked digitally and did not have any production or transportation costs. Focusing on firms independent of these criteria in follow-up studies would provide more insights into these dynamics. Another possibility to understand the scope of accessibilities would be to calculate the transport accessibility for additional (innovation) specific populations, for example, for all patent inventors or university students. This analysis is not included in this dissertation but could give insights into the complex relationships between accessibilities and different population groups.

Additionally, there is the long-term effect that increased innovation activity in one area might have on local accessibility. Some locations may experience a lasting impact on local transport infrastructure due to higher startup rates and an increased inflow of established firms. Accessibility could also be endogenous to firm and regional performance, particularly in the long term. Especially when regarding Chapter 3 and 4, it would be interesting to investigate whether accessibility changes over time in regions with high levels of firm entry, such as the impact of new railroad lines like the Munich-Berlin line implemented in 2017 in Germany, potentially leading to a different assessment of accessibility and a higher number of long-distance commuters. Examining sector-specific subsidy programs could also yield further insights into this topic. Additionally, differences in the level of digitization in companies could affect my findings, with startups that rely less on in-site work and lack fixed production sites responding differently to the availability of local human capital. The growing trend of remote work could potentially lessen the impact of local accessibility. Another possible inquiry I would like to investigate is how bicycle accessibility factors into overall mobility, especially in urban settings. Many founders in Chapter 3 mentioned commuting by foot or bike. Accordingly, establishing safe bike and foot paths could substitute car or public transport on short distances in the city.

In summary, the results presented in this thesis provide numerous opportunities for further investigation. The intricate interplay between a location's accessibility and firms and entrepreneurs necessitates a thorough understanding of the underlying economic mechanisms by policymakers. This dissertation, therefore, significantly contributes to advancing our knowledge of the economics of location accessibility and economic and innovation performance. It highlights vital factors and presents untried queries for future exploration by contextualizing the insights in the dynamic between location accessibility and innovation and entrepreneurship.

Appendix

Table A.0.1: Number of inhabitants per city urban center by OECD definition of city sizes; see Dijkstra et al. (2019).

Urban center sizes in population	
S	50 000 - 100 000
M	100 000 - 250 000
L	250 000 - 500 000
XL	500 000 - 1 000 000
XXL	1 000 000 - 5 000 000
Global city	of more than 5 000 000

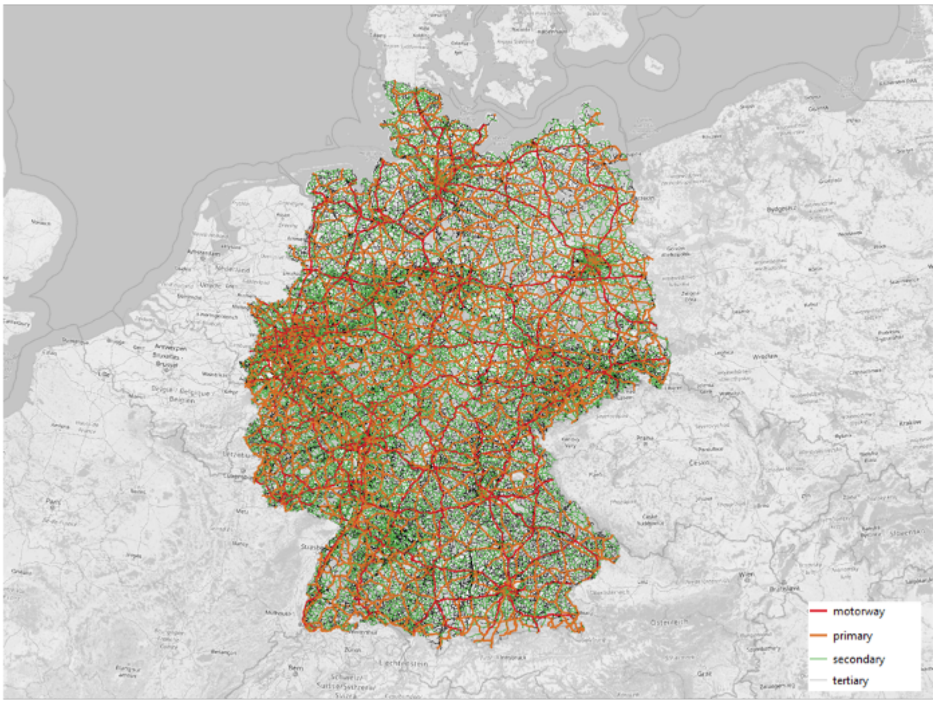
Figure A.0.1: Accessibilities of 40 German Cities

			General population				Employment Population				Research Employment Population				Competitive Employment			
City name	Population	Density	Car (cong.)	Car (free)	Local BMT	LD Rail	Car (cong.)	Car (free)	Local BMT	LD Rail	Car (cong.)	Car (free)	Local BMT	LD Rail	Car (cong.)	Car (free)	Local BMT	LD Rail
Berlin	3450393	high	0,383	0,412	0,762	0,522	0,381	0,408	0,736	0,536	0,628	0,652	0,6	0,698	0,469	0,811	0,51	0,492
Hamburg	1696983	high	0,382	0,396	0,418	0,382	0,4	0,413	0,479	0,442	0,452	0,471	0,249	0,375	0,497	0,83	0,624	0,49
München	1354747	high	0,403	0,420	0,543	0,431	0,445	0,459	0,717	0,543	0,625	0,621	0,745	0,751	0,517	0,862	0,738	0,576
Köln	1018652	high	0,903	0,918	0,536	0,714	0,911	0,925	0,563	0,759	0,947	0,95	0,39	0,77	0,541	0,921	0,571	0,52
Frankfurt am Main	696156	high	0,56	0,675	0,481	0,655	0,591	0,716	0,673	0,778	0,795	0,928	0,362	0,782	0,558	0,965	0,826	0,623
Düsseldorf	658505	high	0,936	0,957	0,694	0,795	0,944	0,963	0,688	0,827	0,855	0,886	0,282	0,721	0,527	0,917	0,598	0,552
Stuttgart	578738	high	0,473	0,555	0,407	0,492	0,504	0,589	0,486	0,559	0,638	0,732	0,301	0,577	0,49	0,908	0,739	0,509
Essen	567789	high	0,942	0,947	0,674	0,772	0,944	0,949	0,593	0,775	0,813	0,83	0,31	0,672	0,532	0,906	0,505	0,544
Dortmund	567391	high	0,851	0,882	0,444	0,641	0,851	0,883	0,377	0,633	0,773	0,808	0,191	0,53	0,541	0,926	0,435	0,493
Leipzig	519624	high	0,406	0,406	0,208	0,295	0,412	0,412	0,213	0,316	0,653	0,636	0,262	0,47	0,486	0,789	0,594	0,472
Braunschweig	244046	high	0,454	0,470	0,141	0,174	0,46	0,476	0,136	0,187	0,637	0,648	0,187	0,289	0,491	0,823	0,567	0,264
Chemnitz	240061	high	0,366	0,381	0,143	0,151	0,37	0,385	0,139	0,161	0,478	0,497	0,088	0,202	0,432	0,728	0,529	0,336
Kiel	237510	high	0,235	0,236	0,143	0,152	0,239	0,239	0,138	0,166	0,273	0,274	0,125	0,179	0,329	0,537	0,462	0,263
Aachen	236597	high	0,865	0,835	0,272	0,421	0,851	0,822	0,248	0,432	0,739	0,718	0,265	0,527	0,382	0,639	0,459	0,304
Halle (Saale)	229381	high	0,411	0,415	0,127	0,288	0,417	0,42	0,131	0,312	0,671	0,656	0,178	0,487	0,49	0,799	0,534	0,471
Magdeburg	227520	high	0,397	0,408	0,081	0,108	0,402	0,412	0,091	0,113	0,606	0,608	0,079	0,144	0,468	0,776	0,66	0,191
Krefeld	221926	high	0,927	0,914	0,509	0,569	0,929	0,914	0,465	0,572	0,729	0,745	0,14	0,465	0,469	0,793	0,452	0,409
Freiburg (Breisgau)	211934	high	0,469	0,470	0,092	0,165	0,476	0,478	0,099	0,178	0,463	0,465	0,244	0,35	0,317	0,522	0,507	0,245
Lübeck	208723	high	0,295	0,293	0,165	0,153	0,3	0,299	0,158	0,166	0,321	0,328	0,04	0,112	0,402	0,654	0,426	0,264
Mainz	200254	high	0,653	0,692	0,293	0,515	0,677	0,721	0,314	0,574	0,897	0,926	0,208	0,643	0,542	0,936	0,56	0,483
Cottbus	99189	high	0,268	0,271	0,061	0,149	0,262	0,265	0,063	0,155	0,33	0,336	0,034	0,176	0,304	0,498	0,504	0,225
Witten	96263	high	0,849	0,884	0,431	0,679	0,85	0,885	0,369	0,671	0,785	0,816	0,197	0,569	0,527	0,905	0,382	0,508
Kaiserslautern	95697	high	0,536	0,557	0,078	0,338	0,545	0,569	0,082	0,367	0,694	0,712	0,105	0,447	0,425	0,725	0,475	0,392
Iserlohn	94342	high	0,76	0,802	0,251	0,489	0,761	0,804	0,213	0,49	0,722	0,764	0,059	0,406	0,509	0,875	0,4	0,393
Schwerin	92181	high	0,328	0,326	0,07	0,152	0,327	0,325	0,07	0,16	0,433	0,439	0,018	0,154	0,412	0,667	0,316	0,227
Düren	89045	high	0,844	0,826	0,196	0,362	0,835	0,819	0,176	0,373	0,794	0,781	0,166	0,41	0,429	0,717	0,364	0,271
Esslingen (Neckar)	87295	high	0,444	0,525	0,303	0,452	0,472	0,558	0,353	0,505	0,576	0,684	0,188	0,519	0,468	0,872	0,566	0,474
Ludwigsburg	86355	high	0,522	0,554	0,311	0,429	0,552	0,586	0,344	0,477	0,686	0,721	0,153	0,457	0,527	0,892	0,584	0,442
Hanau	85887	high	0,61	0,632	0,347	0,62	0,635	0,663	0,402	0,697	0,83	0,846	0,184	0,713	0,545	0,913	0,604	0,606
Tübingen	82636	high	0,428	0,478	0,221	0,287	0,452	0,504	0,235	0,311	0,576	0,634	0,294	0,425	0,433	0,771	0,498	0,337
Lichtenfels	24393	medium	0,43	0,431	0,042	0,161	0,439	0,442	0,041	0,182	0,528	0,528	0,015	0,215	0,417	0,68	0,38	0,265
Blieskastel	21393	low	0,451	0,457	0,082	0,135	0,452	0,461	0,085	0,146	0,501	0,512	0,057	0,167	0,326	0,545	0,37	0,195
Duderstadt	21160	medium	0,336	0,353	0,062	0,097	0,338	0,357	0,056	0,102	0,469	0,483	0,1	0,153	0,353	0,594	0,372	0,16
Greiz	20858	medium	0,32	0,335	0,056	0,094	0,324	0,34	0,049	0,096	0,412	0,435	0,013	0,105	0,383	0,648	0,344	0,197
Neustrelitz	20377	medium	0,203	0,195	0,03	0,037	0,197	0,19	0,029	0,039	0,268	0,263	0,005	0,04	0,28	0,443	0,376	0,089
Burgwedel	20106	medium	0,49	0,501	0,14	0,246	0,498	0,509	0,153	0,267	0,584	0,597	0,075	0,243	0,513	0,849	0,34	0,306
Kleinmachnow	19749	high	0,413	0,420	0,552	0,376	0,413	0,418	0,54	0,386	0,746	0,713	0,612	0,607	0,5	0,823	0,415	0,367
Bad Waldsee	19435	medium	0,33	0,336	0,032	0,098	0,346	0,352	0,03	0,105	0,33	0,347	0,003	0,082	0,369	0,597	0,224	0,206
Dingolfing	17910	medium	0,309	0,313	0,012	0,012	0,327	0,33	0,026	0,017	0,361	0,359	0,001	0,007	0,372	0,604	0,657	0,155
Zossen	17251	low	0,369	0,366	0,154	0,194	0,365	0,362	0,148	0,197	0,561	0,548	0,157	0,262	0,43	0,693	0,193	0,207

Accessibilities of 40 German cities of small, medium, and large size, with population size and population density. Color-coding corresponds to the accessibility value (low to high: from red to green).

A.1 Location-based Accessibilities and Innovation Performance

Figure A.1.1: Car Road Network in Germany



Adapted from Moeckel et al. (2020).

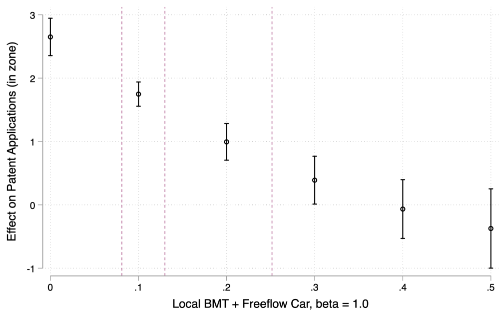
Table A.1.1: Interdependencies between Modes of Transport with Freeflow Car Accessibility

	Patent Applications Local BMT	Patent Applications LD Rail	PIP Local BMT	PIP LD Rail
Freeflow Car	5.008***	4.912***	2.046***	2.650***
	(0.824)	(0.728)	(0.139)	(0.151)
Long-distance (LD) Rail	9.917***		6.377***	
	(3.005)		(0.673)	
LD Rail × LD Rail	0.566		-2.873	
	(5.765)		(1.747)	
LD Rail × Freeflow Car	-19.246***		-2.683*	
	(5.264)		(1.145)	
LD Rail^2 Freeflow Car	8.722		-4.628*	
	(7.250)		(2.173)	
Local Bus, Metro, Tram (BMT)		9.666**		10.595***
		(3.689)		(0.930)
Local BMT^2		0.104		-14.297***
		(5.733)		(2.018)
Local BMT × Freeflow Car		-19.427**		-9.770***
		(6.297)		(1.706)
Local BMT^2× Freeflow Car		12.006		7.446*
		(9.181)		(3.081)
Manu. Firms (ln)	-1.016***	-1.028***	0.349***	0.373***
	(0.118)	(0.119)	(0.024)	(0.024)
Service Firms (ln)	1.025***	1.019***	0.572***	0.606***
	(0.096)	(0.097)	(0.019)	(0.019)
Small Firms (%)	-0.454	-0.472	0.329**	0.265*
	(0.700)	(0.700)	(0.106)	(0.107)
Young Firms (%)	0.106***	0.106***	0.005***	0.005***
	(0.004)	(0.004)	(0.001)	(0.001)
Area Size (ln)	-0.425***	-0.390***	0.217***	0.209***
	(0.080)	(0.082)	(0.019)	(0.021)
Border Region	0.110	0.043	0.019	-0.042
	(0.213)	(0.213)	(0.056)	(0.056)
Constant	21.160***	21.303***	-1.175***	-1.297***
	(0.413)	(0.420)	(0.079)	(0.088)
R-squared	0.155	0.154	0.668	0.662
Observations	10042	10042	10042	10042

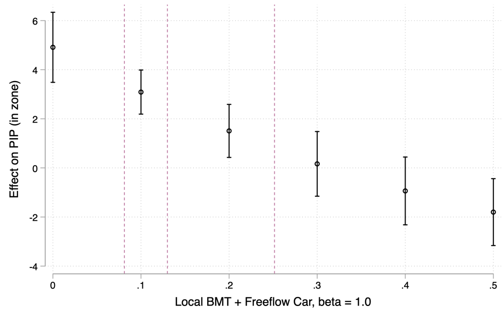
Notes: Ordinary Least Squares (OLS) are used to estimate all models. Each observation corresponds to a given zone with an accessibility. The standard error is clustered at the zone level. Significance noted as: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure A.1.2: Result Graphs of Interdependencies Between Modes of Transport with Freeflow Car Accessibility

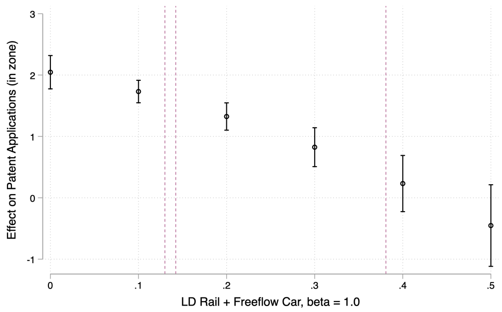
(a) Patent Appls: Local BMT + Freeflow Car



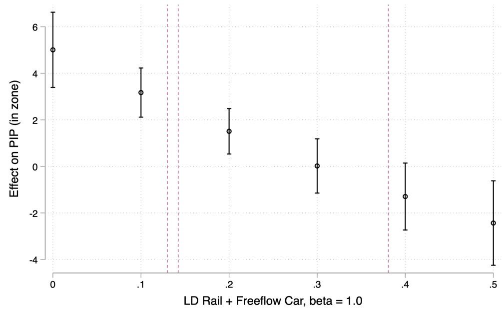
(b) PIP: Local BMT + Freeflow Car Car



(c) Patent Appls: LD Rail + Freeflow Car Car



(d) PIP: LD Rail + Freeflow Car

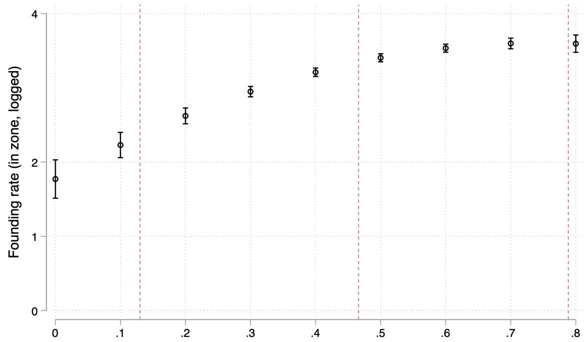


Accessibility weights at $\alpha = 1.0$, $\beta = 1.0$. Average marginal effects of variable with 95% CIs. Dotted lines mark the accessibility mean, median, and 95th percentile.

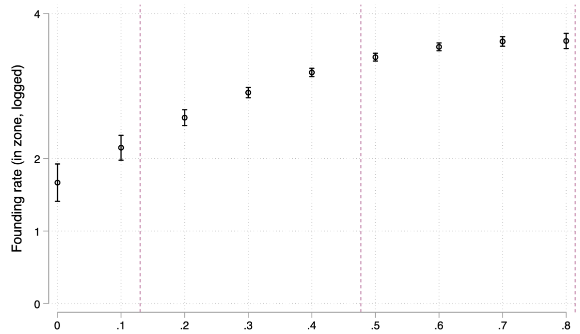
A.2 Location Choice of Entrepreneurs and the Role of Transport Accessibility

Figure A.2.1: Result Graphs for the Research Employee Population Accessibility

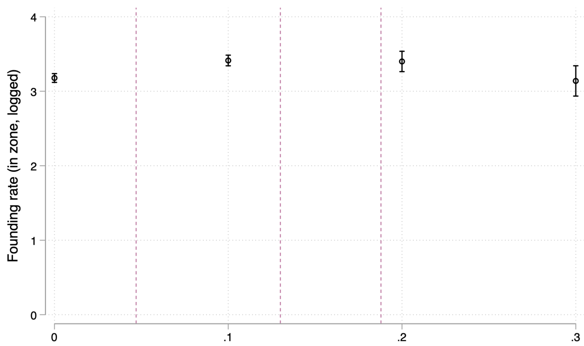
(a) Cong. car



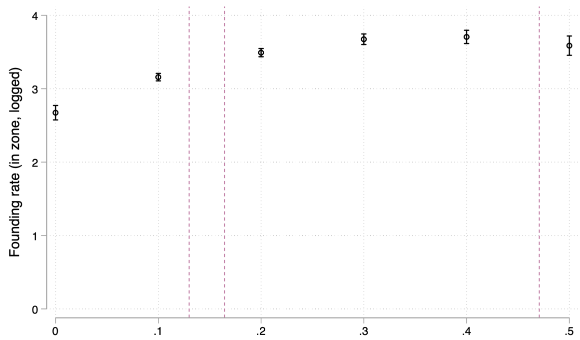
(b) Freeflow car



(c) Local BMT



(d) LD rail



Accessibility weights at $\alpha = 1.0$, $\beta = 1.0$. Average marginal effects of variable with 95% CIs. Dotted lines mark the accessibility mean, median, and 95th percentile.

Table A.2.1: Negative Binomial Regression Results

Startup Founding Rate General Population	Cong. Car	Freeflow Car	Local BMT	LD Rail
Cong. Car	2.85***(0.62)			
Cong. Car^2	-2.65*** (0.66)			
Freeflow Car		2.77*** (0.61)		
Freeflow Car^2		-2.55*** (0.65)		
Local BMT			4.27*** (0.63)	
Local BMT^2			-6.84*** (1.24)	
LD Rail				2.74*** (0.47)
LD Rail^2				-3.60*** (0.84)
Constant	-0.14 (0.36)	-0.11 (0.35)	0.15 (0.32)	0.14 (0.32)
Controls	✓	✓	✓	✓

Startup Founding Rate Employee Population	Cong. Car	Freeflow Car	Local BMT	LD Rail
Cong. Car	3.00*** (0.61)			
Cong. Car^2	-2.74*** (0.66)			
Freeflow Car		2.88*** (0.60)		
Freeflow Car^2		-2.60*** (0.64)		
Local BMT			4.13*** (0.60)	
Local BMT^2			-6.22***	
LD Rail				2.60*** (0.45)
LD Rail^2				-3.13*** (0.75)
Constant	-0.19 (0.36)	-0.14 (0.35)	0.23 (0.32)	0.12 (0.32)
Controls	✓	✓	✓	✓

Startup Founding Rate Research Employee Population	Cong. Car	Freeflow Car	Local BMT	LD Rail
Cong. Car	1.28* (0.55)			
Cong. Car^2	-0.88 (0.54)			
Freeflow Car		1.32* (0.53)		
Freeflow Car^2		-0.90 (0.51)		
Local BMT			2.93*** (0.62)	
Local BMT^2			-4.72*** (1.25)	
LD Rail				1.92*** (0.42)
LD Rail^2				-2.11** (0.66)
Constant	-0.19 (0.36)	-0.14 (0.35)	0.23 (0.32)	0.12 (0.32)
Controls	✓	✓	✓	✓
α (logged)	1.58*** (0.02)	1.58*** (0.02)	1.58*** (0.02)	1.58*** (0.02)

Observations = 9936. Negative binomial regressions with standard deviation in brackets.
$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

A.3 The Role of Location-based Accessibility for the Effectiveness of Startup Subsidies

Table A.3.1: Industry Sector Proportions in the Sample

Industry Sector	Subsidy non-recipients	%	Subsidy recipients	%	Total	%
Cutting-edge technology	1,921	76.9	576	23.1	2,497	6.0
High-technology	1,708	79.6	438	20.4	2,146	5.2
Technology-related services	7,799	85.6	1,313	14.4	9,112	21.9
Software	3,062	85.9	501	14.1	3,563	8.6
Non-technological industries	3,38	78.7	917	21.3	4,297	10.3
Knowledge-based services	3,318	88.6	427	11.4	3,745	9.0
Business-related services	2,598	86.0	422	14.0	3,020	7.3
Creative services	1,861	88.2	248	11.8	2,109	5.1
Other services	2,246	80.8	534	19.2	2,780	6.7
Construction	3,492	81.2	810	18.8	4,302	10.3
Trade	3,284	80.5	794	19.5	4,078	9.8
Total	34,669	83.2	6,980	16.8	41,649	100

Table A.3.2: Correlation Table of Outcome Variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) R&D Expenditure	1						
(2) Tangible Investments	0.750	1					
(3) Employees	0.367	0.334	1				
(4) Revenue	0.323	0.226	0.797	1			
(5) Investments	0.285	0.220	0.574	0.590	1		
(6) Innovation	0.441	0.339	0.437	0.449	0.361	1	
(7) Exit	-0.067	-0.044	-0.120	-0.146	-0.115	-0.053	1

Table A.3.3: Accessibility Correlation Table

Accessibility Mode Population	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1) Car (congested)	1											
(2) BMT	0.472	1										
(3) LD Rail	0.660	0.832	1									
(4) LD Bus	0.388	0.904	0.774	1								
Employees												
(5) Car (congested)	0.998	0.477	0.671	0.390	1							
(6) BMT	0.409	0.982	0.819	0.890	0.421	1						
(7) LD Rail	0.622	0.826	0.994	0.768	0.638	0.831	1					
(8) LD Bus	0.346	0.902	0.776	0.978	0.356	0.923	0.789	1				
Research Employees												
(9) Car (congested)	0.789	0.543	0.756	0.489	0.804	0.534	0.752	0.492	1			
(10) BMT	0.191	0.838	0.661	0.785	0.206	0.889	0.691	0.839	0.459	1		
(11) LD Rail	0.455	0.799	0.920	0.757	0.474	0.828	0.940	0.794	0.728	0.832	1	
(12) LD Bus	0.216	0.775	0.666	0.818	0.229	0.818	0.690	0.868	0.494	0.937	0.830	1

Notes: BMT = Bus, metro, tram; LD = Long-distance.

Table A.3.4: Correlation Table of Input Variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) University education	1										
(2) Vocational training	-0.276	1									
(3) Master craftsperson	-0.285	-0.251	1								
(4) (Founder) Age	0.138	-0.073	-0.034	1							
(5) Industry experience	-0.048	-0.044	0.178	0.572	1						
(6) Entrepr. experience	0.169	-0.022	-0.108	0.250	0.096	1					
(7) Failure experience	0.017	0.026	-0.037	0.012	-0.022	0.329	1				
(8) Opportunity-driven	0.111	-0.062	-0.054	-0.029	-0.064	0.104	0.007	1			
(9) Team	0.293	0.041	-0.049	0.150	0.052	0.271	0.039	0.129	1		
(10) Female founder	0.074	0.073	-0.086	0.071	-0.040	-0.008	-0.003	0.027	0.195	1	
(11) Startup age	-0.002	-0.042	0.046	0.188	0.217	-0.052	-0.238	-0.006	0.011	-0.014	1
(12) Limited liability	0.284	-0.132	-0.157	0.224	0.057	0.311	0.048	0.145	0.340	-0.012	-0.043
(13) Tangible Assets	-0.041	-0.006	0.046	-0.044	0.003	0.015	0.026	-0.010	-0.041	-0.035	0.005
(14) Patent(s)	0.013	-0.006	-0.011	0.027	0.010	0.026	0.018	0.005	0.013	0.010	-0.035
(15) Export activity	0.109	-0.060	-0.078	0.111	0.048	0.082	-0.028	0.054	0.101	-0.027	0.137
(16) Capacity utilization	0.034	-0.067	0.031	-0.012	0.072	-0.006	-0.011	0.018	0.043	-0.033	0.075
(17) East Germany	0.004	0.016	0.013	-0.015	-0.011	-0.018	-0.015	-0.023	-0.027	0.012	0.029
(18) R&D-Expenditure	0.143	-0.107	-0.084	0.116	0.054	0.119	-0.111	0.090	0.139	-0.043	0.253
(19) Employees	0.050	-0.044	0.052	0.157	0.181	0.022	-0.254	0.042	0.170	0.011	0.627
(20) Revenue	0.004	-0.040	0.053	0.130	0.179	-0.040	-0.236	0.001	0.029	-0.040	0.672
(21) Tangible Investment	-0.004	-0.042	0.056	0.055	0.091	-0.022	-0.172	0.017	0.027	-0.046	0.339
(22) Profit	0.002	0.003	0.004	-0.001	0.008	-0.007	0.000	0.007	0.004	0.001	0.007

Variables	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
(12) Limited liability	1										
(13) Tangible Assets	-0.147	1									
(14) Patent(s)	0.031	-0.001	1								
(15) Export activity	0.226	-0.022	0.017	1							
(16) Capacity utilization	0.057	-0.002	0.004	0.054	1						
(17) East Germany	-0.064	-0.006	-0.004	-0.049	0.015	1					
(18) R&D-Expenditure	0.243	-0.001	-0.017	0.284	0.072	-0.018	1				
(19) Employees	0.125	-0.050	-0.037	0.168	0.107	0.017	0.362	1			
(20) Revenue	0.000	0.011	-0.033	0.171	0.114	0.014	0.273	0.701	1		
(21) Tangible Investment	0.004	0.026	-0.019	0.102	0.089	0.012	0.242	0.523	0.583	1	
(22) Profit	0.003	-0.005	0.000	-0.009	0.002	0.002	0.001	0.006	0.006	-0.002	1

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