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**ORIGINAL PAPER** 



# Tech hubs within cities—determinants and dynamics

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## Abstract

This paper explores the microgeographic determinants of firm birth activity and relocation patterns in the digital economy simultaneously. The study investigates the spatial dynamics of young firms within Berlin, Hamburg, and Munich using geo-coded data of firm births and relocation from 2009 to 2016 aggregated at a  $1 \times 1$  km<sup>2</sup> grid level. The panel fixed effect regression models examine the impact of changes within persistent city structures on the location choices using several control variables. The findings suggest that firm clustering, commercial building density, and higher rent prices positively influence firm births, while the impact of knowledge institutions in the neighborhood is mixed. Relocation patterns highlight the role of proximity to competitors, with higher prices in areas not deterring relocations. These findings contribute to understanding firm location choices within cities by considering the two avenues of growth and highlight the future need for further investigations on the microgeography of firm growth dynamics.

JEL classification R10

# **1** Introduction

The inner city location choices of new and young digital firms under ten years are of major interest for urban policymakers as it has important implications on where to intervene with tax money to spur on growth by means of innovation or industry development to ensure future competitiveness. This paper examines the microgeographic determinants of firm birth activity and relocation patterns of young digital firms within cities. I geocode and aggregate 24,614 firm births between 2009 and 2016 in Hamburg, Berlin, and Munich on  $1 \times 1 \text{ km}^2$  grids. I complement these firm data with a granular dataset on the built environment,

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prices, and knowledge infrastructure. With this empirical setup, I explore spatial characteristics that determine the rise of startup clusters and hubs within the city.

Andersson and Larsson (2021) and De Groot et al. (2016) highlight the importance of examining the quality of entrepreneurship at a granular level, suggesting a fine-grained analysis of entrepreneurship clusters and the factors that influence their location choices. The digital industry is of interest as it complements many, almost all other sectors, contributes significantly to GDP, demands high skilled and well-payed employees, and offers few negative externalities in terms of land use and emissions. Further, startup hubs have a crucial role to play in shaping innovation systems, production systems, and urban economic development, particularly in the context of the knowledge-based economy (Zandiatashbar et al. 2019). Unlike traditional industries tied to physical locations, digital firms operate in a virtual environment. This geographical independence enables the examination of agglomeration benefits without being constrained by traditional spatial boundaries. The digital industry also experiences quick innovation cycles (Bogachov et al. 2021). Proximity to other firms can accelerate the pace of innovation through the rapid dissemination of new ideas and technologies. This is why studying firm birth patterns and relocation of young firms simultaneously offers insights into adaption strategies to these fast pacing business environments.

As young firms are often more dynamic and responsive to market changes (Adelino et al. 2017), studying their relocation behavior provides insights into the economic vibrancy and adaptability of neighborhoods, as these firms may be indicative of emerging business trends. Policymakers can leverage insights into the location of digital firms to nurture innovation ecosystems, fostering an environment conducive to creativity, research, and development. Further, analyzing the distribution of digital firms helps to develop strategies to mitigate risks and increase the adaptability of urban areas, thereby promoting long-term sustainable growth and stability. The location of digital firms also contributes to the social and cultural fabric of a city (Foord 2013; Hospers 2003; Musterd and Gritsai 2013). Policymakers can consider these factors in urban planning to create vibrant, diverse and inclusive urban environments that attract and retain talent.

Examining the location of digital firms within a city at a high resolution, the  $1 \times 1$  km grid, allows for a nuanced understanding of agglomeration benefits. Furthermore, understanding firm distribution at this fine-grained resolution enables policymakers and urban planners to pinpoint specific neighborhoods or areas where digital firms tend to cluster. This information is vital for targeted spatial planning initiatives. This information can be used to design policies that support the development of specific neighborhoods as hubs for digital firms. Targeted economic development strategies can foster innovation and entrepreneurship within these clusters.

The cities of Berlin, Hamburg, and Munich are of particular interest as showing the highest firm birth dynamics in Germany. Berlin's digital industry employs 130,900 people (36 per 1000 inhabitants), while Hamburg employs 70,200 (38 per 1000 inhabitants) and Munich 92,770 (63 per 1000 inhabitants) (Bundesagentur für Arbeit 2021; City of Munich 2022). Thus, Germany and these three cities in particular with dense tight infrastructure and spatially disaggregated information on digital firms, offer an excellent opportunity to examine the growth dynamics of the industry and their importance in fostering startup ecosystems in the digital industry.

A growing number of studies consider the microgeographic behavior of firms and the benefits of clustering (Arzaghi and Henderson 2008), the effects of localization and urbanization (Andersson et al. 2019), and the importance of the built environment (Roche 2020). In terms of the microgeography of the digital industry, scholars have shown that the industry is highly clustered in space with a tendency toward CBDs (Duvivier and Polèse 2018; Duvivier et al. 2018; Zandiatashbar et al. 2019; Méndez-Ortega and Arauzo-Carod 2020).

First, this paper contributes to the literature by applying panel fixed effect models covering 2009–2016 to assess what changes within persistent urban structures affect the location choices of young firms. Second, to the best of my knowledge, this paper is the first to consider the relocation of young digital firms at the microgeographic level. Andersson and Larsson (2021) emphasize that a firm's relocation signals an optimization decision, a deliberate substitution of one location for another, whereas newly established firms are not bound by previous location choices. A direct comparison of the location choices of new and existing firms sheds new light on the importance of inner city location factors.

The results for firm births indicate significant firm clustering at the  $1 \times 1$  km grid level, suggesting that the presence of similar firms in an area increases the establishment of new firms. Commercial building density that partly proxy diversity of economic activity in neighborhoods attracts new firms, while household numbers have no significant influence. Higher rent prices are associated with increased firm births, indicating a willingness to pay for agglomeration benefits. The impact of knowledge institutions is mixed, with research institutes showing negative effects on firm births, while new higher education institutions attract relocating firms. Relocation patterns mirror firm birth patterns, emphasizing the role of proximity to competitors. Higher prices in areas do not deter relocations, suggesting other factors at play. These findings contribute to understanding firm location choices and the role of knowledge infrastructure, but further investigation is needed to unravel the complex dynamics at play.

The paper proceeds as follows: The next chapter provides a brief overview of the spatial determinants of location choices within cities. The third chapter presents the data and the fourth chapter the methodology. After that, the empirical results are presented. The robustness section discusses possible caveats and the last chapter concludes.

#### 2 Spatial determinants of firm location within cities

# 2.1 Firm birth and agglomeration externalities

One of the major reasons why cities exist and continue to grow is agglomeration advantages for firm productivity and growth. Particularly important are clusters of external scale economies (or externalities) specific to a particular location, driven by underlying factors such as shared infrastructure, the impact of a thick labor market on matching effects, and the dissemination of ideas and information through learning processes (Duranton and Puga 2004). For new and young firms, being the focus of this paper, constraints on (technical) capabilities outside their existing knowledge are likely to cause problems (Schartinger et al. 2001), especially for the digital industry being dominated by small firms (more than 90% of all ICT firms had less than 10 employees in 2017; Destatis 2021). Because of high costs for internalizing knowledge, firms rely on retrieving outside knowledge. These spillovers have been shown to work on small spatial scales within cities, which is why being close to knowledge sources is crucial for small firms (Van Soest et al. 2006; Arzaghi and Henderson 2008; Larsson 2014; Jang et al. 2017; Rammer et al. 2020; Roche 2020). As labor market effects mostly work on citywide and even regional levels (labor market regions) and firms can benefit from shared effects for the whole city, the main benefit from proximity in neighborhoods is derived from knowledge exchange. In this context, the scholarly debate on agglomeration effects reflects what kind of knowledge spillovers and business environments are conducive to firm development and competitiveness. Studies on firm-to-firm externalities find that localizationsimilar, same industry knowledge (Porter 1990) and urbanization [diverse, other industries-knowledge Jacobs (1969)] play a vital role for firm productivity. It is still a broad discussion, whether more specialization or more diversification of the urban environment is beneficial for productivity growth.

Overall, it seems that both externalities coexist but differ in their spatial distribution and attenuation within cities (Andersson and Larsson 2021). However, recent studies show that these effects seem to operate on different spatial scales: localization externalities operate in neighborhoods of one square kilometer and less which is why similar firms cluster in that radius (Rosenthal and Strange 2008; Lavoratori and Castellani 2021). This knowledge sources are found to primarily be similar firms, as shown by Arzaghi and Henderson (2008) for advertising firms in Manhattan. Similarly, Andersson et al. (2019) show that intra-industry spillovers operate at smaller spatial scales than spillovers arising from a diverse industry mix within metropolitan cities. This is the main reason for the significant clustering of industries within cities. For digital firms, Beaudry and Schiffauerova (2009) emphasize a strong benefit from clustering of similar firms.

In contrast, the benefits of urbanization operate at neighborhood and city level. For knowledge-intensive firm births, the potential benefits of 'cross-fertilization' between industries to generate new ideas and innovation stand out (Andersson et al. 2019). Frenken et al. (2007) argue that it is not a generic diversity but local variety of related firms that provides the know-how for knowledge transfers. Mainly, spill-overs require at least some similarity in knowledge bases, competencies or skills, labor pools, and technologies to ensure absorptive capacity (Boschma 2005). Therefore, the potential for inter-firm knowledge spillovers is higher for firms operating in similar industries, that is, they share 'economic proximity' (Van Oort et al. 2015). Notwithstanding the heterogeneity of the sector itself, digital companies that combine several areas of knowledge enhance their competitiveness. First, a digital firm needs knowledge about the fundamentals of its business model that is technological skills (Grillitsch et al. 2019). Second, business knowledge such as accounting and sales is needed. Third, scholars increasingly acknowledge the role of aesthetics

and design for innovation (Secundo et al. 2020). Tödtling and Grillitsch (2015) find firms with internal competencies in design and product or process management to be more innovative. Therefore, technological knowledge or data science, business knowledge, and design competencies are associated with digital firms. Motivated by this literature, this paper uses a broad sample of digital firms, that is, strict NACE classifications are loosened and firms operating on a digital business model are considered (see Sect. 3 for details). Nevertheless, in the further course of this paper this is interpreted as localization economics in the sense of Rosenthal and Strange (2008); Lavoratori and Castellani (2021), and Arzaghi and Henderson (2008). Based on this literature, I assume that firm birth in the digital industry is clustered within cities as firms can retrieve knowledge from firms with similar knowledge stocks. Hence, hypothesis (1) is that *firm birth in the digital industry emerges in neighborhood environments where firms operating on a similar business model and knowledge stocks are already established, capturing localization economics.* 

Besides industry knowledge, knowledge institutions such as Higher Education Institutions and Research Institutes generate externalities. However, there is less research on the extent of spatial proximity for university-industry spillovers than for intra-industry spillovers. Over the past decades, universities have been called upon to open the door to the 'ivory tower' and play the roles of local powerhouses of knowledge transfer to foster entrepreneurship and growth (Geuna and Muscio 2009; Ghinamo 2012). Good et al. (2019) and Fabiano et al. (2020) show manifold university-industry linkages used for public–private knowledge transfers in their literature reviews on technology transfer ecosystems in academia. Especially tacit universityindustry spillovers via incubators require proximity (Fabiano et al. 2020). Kerr and Kominers (2015) point to individual channels operating at the regional level, such as through the labor market. Therefore, firms located near knowledge institutions should gain some 'topup' advantage via tacit knowledge transfers that are not transferable trough other channels.

For example, Rammer et al. (2020) identify proximity to research institutes and universities as a distinctive feature for the innovativeness of firms in Berlin. In contrast, an investigation of ICT-employment density using microdata for three Canadian cities finds no significant effect for research universities when controlling for other location factors, albeit the employment is clustered in central neighborhoods (Duvivier et al. 2018). Duvivier et al. (2018) hence conclude that university spillovers must be relevant for all locations within cities. Overall, there is very little evidence on the spatial scale of university-industry spillovers within cities.

Beyond the role of knowledge transfer, universities and especially their students are often seen in the literature in the context of hip, urban neighborhoods (Hutton 2004). This also relates to Florida (2002) and the creative class that often overlap with student neighborhoods and presumably new firms and startup hubs (Hutton 2004). However, these neighborhoods and urban milieus are particularly challenging to measure empirically, because the components that make up local coolness are complex and regional science is still working to decipher them. Nevertheless, given the role of universities in the local knowledge base and the assumption that there are

at least students in neighborhoods with universities,<sup>1</sup> I assume in hypothesis (2) that *Universities contribute to firm birth at the neighborhood level*.

In addition to the benefits of clustering and knowledge spillovers, the overall characteristics of the neighborhood, such as the built environment, i.e., urban density, are thought to influence the location choice of newly established firms. Numerous studies provide evidence that higher density of the built environment contributes to agglomeration benefits, leading to higher productivity and innovation (Andersson et al. 2019; Melo et al. 2009; Knudsen et al. 2008). Higher urban density is also associated with increased productivity and incomes in cities, as denser areas tend to offer more opportunities for economic activities and interactions (Duranton and Puga 2020; Ahlfeldt and Pietrostefani 2019). Further, an increased density in commercial buildings and a larger number of firms there come an increased diversity of human capital in neighborhoods (Jacobs 1969; Henderson et al. 2003). It is important to note that this increased productivity comes at the expense of higher costs, particularly in terms of housing and office rentals. Nonetheless, new firms in the digital industry, which are often small and require minimal physical space, have demonstrated a willingness to absorb these costs in dense, central neighborhoods due to the outweighing agglomeration advantages (Polèse 2014). Hypothesis (3) therefore posits that a higher density of the built environment, that is localization economics, has a positive impact on the clustering of digital firms.

#### 2.2 Relocation

When studying firm birth and relocation, it is important to recognize that they are fundamentally different phenomena that should be examined separately (Manjón-Antolín and Arauzo-Carod 2011). Unlike new firms, relocating firms are constrained by former location decisions, face sunk costs, and high costs of relocation by explicitly substituting one location for another. Hence, a move is a costly but critical strategic decision for entrepreneurs as it involves a spatial adjustment to respond to changes in the internal and/or external environment (Lee 2020). As this paper focuses on the relocation behavior of young digital firms, they are expected to be innovative, collaborative, and focused on growth. Unlike established firms that focus on productivity, young firms are expected to adapt more quickly to changing internal circumstances, as they are not yet in a steady-state. I therefore expect them to adjust their location decision to their needs and dependency on outside resources. This is particularly interesting for local policymakers to provide locations not only for firm birth, but also for young firms 'coming of age'.

This study relates to the broader literature on firm relocation. Existing research is mostly conducted at the regional or state level (Brouwer et al. 2004; Kronenberg 2013; Foreman-Peck and Nicholls 2015; Nguyen et al. 2013; Rossi and Dej 2020; Pan et al. 2020). However, none of these papers consider the microgeographic dimension of destinations which is the focus in this paper. It is per se unclear

<sup>&</sup>lt;sup>1</sup> Note that Universities in European cities are more often located in inner cities and less often on large campuses than in the USA.

whether location determinants can be transferred to the micro-environment. Movements between core cities often reflect firms moving from diversified (urbanization economies) to specialized cities (localization economies) (Duranton and Puga 2001). Manufacturing firms start in diversified cities (urbanization economics) until they find an ideal business process, and eventually move to a specialized city (localization economics) when switching to mass production. With emphasis on Beaudry and Schiffauerova (2009) finding for digital firms specifically, who strongly benefit from clustering of similar firms, I do not expect this benefit to diminish for the first eight to ten years of their life cycle in an inner city environment.

Hypothetically, the availability of highly skilled labor should not vary much within the cities. In terms of knowledge infrastructure, Audretsch et al. (2005) note that younger firms will locate closer to universities to compensate for high R&D costs due to their high dependence on knowledge inputs. Moreover, there is also a large variation in rental prices within cities. Therefore, it is unclear whether firms chose lower-cost locations as in the incubator hypothesis (Leone and Struyk 1976) or accept higher prices close to competitors to profit from industry-knowledge spillovers. Given the high level of uncertainty, I hypothesize that *Firm birth and young digital relocates in general favor similar location characteristics* (hypothesis 4).

# 3 Data

The tailor-made dataset encompasses two main components. First, firm-level data on young digital firms are used. Second, I use a rich dataset that includes variables for economic activity, socio-demographic conditions and knowledge infrastructure on a  $1 \times 1$  km square neighborhood level. This enables linking economic activity to neighborhood characteristics within cities to disentangle cluster effects and the underlying mechanisms. The empirical analysis is conducted on the  $1 \times 1$  km grid level and its first-order neighbors (see 3.1).

#### 3.1 Grid-level analysis

The key advantage of using grids is that the position of the squares is independent from economic activity, thus addressing endogeneity issues, while allowing to investigate externalities and spillover effects at small spatial scales. Following Andersson et al. (2019), the latent "true" size of the mentioned externalities is unclear and could possibly cover several squares. To address this issue, this empirical analysis employs two spatial scales, the neighborhood<sup>2</sup> (1×1 km<sup>2</sup> grid denoted by *n*) as well as its first-order neighbors (3×3 km<sup>2</sup> grid indicated by *n*\*). By that, each grid (*n*) has eight neighbor grids (*n*\*). This allows to test for possible decay of the expected effects within cities (see Fig. 1).

<sup>&</sup>lt;sup>2</sup> Neighborhood refers to the spatial level and does not cover a 'functional' neighborhood. The grids refer to standardized EU-INSPIRE Grids.

**Fig. 1** Neighborhood and Grid-Level. The figure visualizes the neighborhoods and the first-order neighbors, similar to Andersson et al. (2019)



The three cities analyzed in this paper are Berlin (920 grids), Hamburg (795 grids), and Munich (350 grids). As the three largest cities in Germany, they all host a strong startup ecosystem with thick knowledge bases. Although they differ in legislative characteristics (Berlin is the capital of Germany and a federal state, Hamburg is a federal state on its own, while Munich is the capital of the federal state Bavaria), they are all considered the economic powerhouse of their regions.

## 3.2 Geo-coded firm-level panel dataset

The firm data allow precise point-level tracking of individual firm locations. The analysis covers companies which entered the market between 2009 and 2016. The data originate from the statutory publications of German corporations and are provided by North Data (2019). Firm information includes date of incorporation, date of termination (if applicable), economic field, description of the company's main business area and address history. The data do not include individual firm information such as financials or the number of employees. As there is no agreed-upon definition of the digital industry, for the purpose of this paper a digital firm is defined as information-technology driven and internet-based. I selected firms using NACE codes: general programming activities, software development, web portals, data processing and the development of web pages, processing, hosting and related activities and web portals<sup>3</sup> (Weber et al. 2018). Yet, standard industry classification systems have limitations, especially for industries that cross-over traditional product categories, such as the digital industry (Oakey et al. 2001). Since digital business models complement many other sectors, firms may be registered in other NACE codes despite running a digital business model. Therefore the resulting sample contains firms characterized by the core knowledge on which their competitiveness ultimately draws. The inclusion of these firms provides a novel approach that offers a deeper understanding of knowledge flows and the notion of diverse and specific economic inputs in local firm environments. The digital industry is a broader term that encompasses a wide range of businesses and economic activities that leverage digital technologies. Thereby, it reflects a transformation of traditional industries

<sup>&</sup>lt;sup>3</sup> 62.01.0, 62.01.1, 62.01.9, 62.02.0, 62.03.0, 62.09.0, 63.11.0, 63.12.0.

through the adoption of digital technologies. As it goes beyond core ICT activities, it also has a broader economic impact. Through the integration of digital technologies in different sectors, it is often associated with transformative innovation and adaptation to technological advancements. The digital industry includes companies like Amazon, Netflix, and Uber. These companies operate in various sectors but are united by their reliance on digital technologies. In contrast, the ICT sector in the narrower sense includes companies like Cisco, Intel, IBM, and telecommunications providers. These companies are more directly involved in developing and providing ICT products and services. In summary, the digital industry is a broader concept that encompasses a wide range of activities across various sectors, while the ICT sector focuses on technologies related to information and communication. The inclusion of these firms provides a novel approach that offers a deeper understanding of knowledge flows and the notion of diverse and specific economic inputs in local firm environments. The digital industry is a broader term that encompasses a wide range of businesses and economic activities that leverage digital technologies. Thereby, it reflects a transformation of traditional industries through the adoption of digital technologies. As it goes beyond core ICT activities, it also has a broader economic impact. Through the integration of digital technologies in different sectors, it is often associated with transformative innovation and adaptation to technological advancements. The digital industry includes companies like Amazon, Netflix, and Uber. These companies operate in various sectors but are united by their reliance on digital technologies. In contrast, the ICT sector in the narrower sense includes companies like Cisco, Intel, IBM, and telecommunications providers. These companies are more directly involved in developing and providing ICT products and services. In summary, the digital industry is a broader concept that encompasses a wide range of activities across various sectors, while the ICT sector focuses specifically on technologies related to information and communication.

For the selection of the sample, with the help of a word-search selection, firms that are not registered in the ICT sector but operate on a digital business model were added to the dataset. First, the description of the identified ICT firms has been analyzed and the most frequently used words related to IT and software have been identified (software development, internet services, IT-services, information technology, and programming). Then, these keywords are used to obtain those firms operating on digital business models with the help of several word combinations. Firms that only distribute their products via a web page have been excluded (main keyword "Online Shop"). For the firms that run an online store, keywords related to "software development" needed to be included. Another company registered in "other livestock farming" develops software for beekeepers, and thus, their initial knowledge base needs to contain strong digital components. The resulting sample encompasses firms which are similar in their requirements in terms of employees as well as knowledge; these are the two factors crucial to their competitiveness. The dataset comprises 24,614 individual firms. On average, there are 2530 newly registered firms per year with a standard deviation of 291. The resulting panel data consist of 101,721 firm-year observations. By this, the data partly capture economic proximity based on shared knowledge bases beyond classical industry classifications.

A firm's location in a given year is its location on 31 December. Relocations are tracked through changes in the registration address. There are 11,046 observed relocations in the dataset, which equals 10.8% of firms relocating per year with a standard deviation of 0.5. The data include all legally independent firms, while branches are not included in the data. Due to this peculiarity in the data, the empirical exercise is likely underestimates the true extent of firm mobility. Establishments that exit the market are excluded from the panel dataset after the year of deletion from the register.

Location is available at the point level. Within the empirical strategy, the firm data are aggregated to the neighborhood/ $1 \times 1$ km<sup>2</sup> grid level (*n*) resulting in the key measure of the number of firms per grid (see Sect. 4). In total, the dataset contains 12,726 grid-year observations for the three cities.<sup>4</sup>

#### 3.3 Location characteristics

The second data part contains neighborhood characteristics from various data sources. The number of commercial buildings and the number of private households are used to capture the firms' local environment, such as the distinction between suburban office parks and dense neighborhoods (Breidenbach and Eilers 2018). Additionally, I am using the average rent price for a 60 m2 apartment as a proxy for real estate values and willingness to pay for amenities as provided in the RWI-GEO-RED dataset. The data originate from ImmobilienScout24, the largest real estate portal in Germany, and is provided by the RWI (RWI and ImmobilienScout24, 2021). To explore the role of knowledge institutions conducive to digital firm clustering, data were collected on the knowledge infrastructure that is Higher Education Institutions (HEI) and research institutes. For HEIs, this includes universities (Universitäten), Universities of Applied Sciences (Fachhochschulen), and Art Schools (Kunst-und Musikhochschulen). The disaggregated dataset contains the point-location of departments (*Fakultäten*) of HEIs. That is, universities which spread over several locations are mapped granularly. The data originate from Hochschulkompass (2020), while the location of departments has been drawn from the HEIs' websites. The number of students is not covered because it is not reliably available over time and locations. Further, the data cover a total of 76 HEIs in 108 unique locations. During the observed time, there are a total of 19 new locations.

For research institutes, the locations of institutes belonging to the four major German research associations (Fraunhofer Institut 2019; Helmholz Gesellschaft 2019; Leibniz Association 2019; Max-Planck-Institute 2019), and institutes funded by the federal states as well as the national government (*Forschungseinrichtungen des Bundes und der Länder*, (OEFW 2016)) are included. For the sake of the empirical analysis, the data on research institutes and HEI are aggregated on the 1×1 km<sup>2</sup> grid level (and its first neighbors).

 $<sup>^4</sup>$  The analysis covers the years 2010–2016 due to the use of lags.

Statistics	Ν	Mean	St. Dev	Min.	Max.
Firm Birth <i>n</i>	12, 726	1.42	4.10	0	79
EDF n (lag)	12, 726	6.40	17.94	0	398
EDF $n^*(lag)$	12, 726	50.56	112.22	0	1, 595
HEI n	12, 726	0.05	0.32	0	7
HEI n*	12, 726	0.44	1.23	0	12
Research Inst. n	12, 726	0.05	0.32	0	8
Research Inst. n*	12, 726	0.38	1.24	0	13
Commercial buildings n	12, 726	319.40	546.78	0	9, 411
Commercial buildings n*	12, 726	2, 506.05	3, 452.23	0	26, 163
prices	12, 726	516.82	129.86	230.01	1, 490.69
Households	12, 726	2, 030.25	2, 450.35	0	15, 539
Movers within n	12, 726	0.07	0.43	0	15
Movers into n	12, 726	0.76	2.59	0	76

 Table 1
 Summary statistics

n refers to the grid-level neighborhood,  $n^*$  refers to the 1st-order neighborhoods, *EDF* refers the number of existing digital firms in the unit of observation

#### 3.4 Descriptive statistics

Table 1 provides summary statistics for digital firms on neighborhood level for Hamburg, Berlin, and Munich covering the years 2009 to 2016. The mean number of new firms per grid is 1.42, while the maximum is 79 indicating a spatial concentration of firms.<sup>5</sup> Further, the highest density of digital firms is a grid with 398 digital firms in one square km. Regarding the relocation of the firms, the table reveals that with a maximum of 76 firms, relocation is, at least for some grids, a similarly important growth factor. However, relocations within grids are less common with only 0.07 in the average grid.

Figure 2 presents the spatial distribution of firms in each city, offering valuable insights into firm birth and relocation dynamics. The left-hand side graphs show the percentage of firms founded in each grid compared to the total number of founded firms in the city each year. Similarly, the right-hand side graphs depict the patterns of relocation. The grids' locations can be found in Fig. 3, with consistent coloring across the firm birth and relocation analyses. Additionally, the top five grids with the highest firm birth shares in 2016 are color-coded accordingly. The figure highlights an interesting trend of digital firms clustering, with approximately six standout grids in each city. Hamburg stands out the most, with one grid consistently displaying significant clustering throughout the study period. Berlin and Munich exhibit a more balanced distribution, although both cities have an orange-colored grid that shows strong growth and increasing competitiveness over time.

<sup>&</sup>lt;sup>5</sup> Grid level and neighborhood level are used synonymously.



**Fig. 2** Digital Firm Birth on Grid-Level for Berlin, Hamburg, and Munich. Notes: The graphs on the lefthand side show the share of firm birth per grid within the cities; the graphs on the right -hand side show the share of in-movers per city. Each line represents the development in one grid. The colored lines show the development of the six best-performing grids (in 2016). The orange line in each graph represents the top performing grid in 2016, followed by the light blue, green, yellow, dark blue, and red. All other grids in gray. Note that the graph for Hamburg has a different scale for better visibility. The legend is left out intentionally. The location of the colored grids is shown in Fig. 3 (color figure online)



**Fig. 3** Maps of the location of high performing grids for firm birth in Hamburg, Berlin, and Munich. Notes: The maps on the left-hand side show the  $1 \times 1$  km grids in the investigated cities and are intended to show where the firm birth hot spots within the cities are located. The colors of the grids match the colors in Fig. 2. The maps on the right-hand side show the OSM Map of the cities for orientation

Turning to relocations, the right-hand side graphs reveal a couple of intriguing findings. Firstly, relocations appear to be slightly less concentrated spatially compared to firm births. However, there is a general preference for the same grids among both firm births and relocations.

It is worth noting that a few grids attract relocations without standing out significantly in terms of firm births.



Fig. 4 Distribution of the frequency of firm birth in neighborhoods

In all cities, four to five grids stand out in firm density. The top performing grids are all next to each other, except for one spatial outlier in each city. Hamburg seems to be uniquely persistent, with a cluster of 10% of firms in one grid at all times. In Berlin and Munich, the firm birth dynamics vary from year to year, but only within five grids (between 3 and 5% of all firm birth). This could be indicative of distinct location characteristics that are not related to inner-core characteristics like amenities. Figure 4 in the appendix shows the distribution of firm birth in the grids. The figure clearly shows that the vast majority of the grids have either never had any firm birth activity or have very rarely had a new firm in a given year.

# 4 Empirical strategy

The following chapter presents the empirical strategy. The first chapter describes the firm data on the neighborhood level on which the dependent variables are built. After that, the empirical setup is described.

# 4.1 Dependent variable

The aim of the paper is to find factors of inner cities and neighborhoods that determine the location choice of digital firms. Therefore, two dependent variables are selected for the empirical analysis. The first dependent variable is the number of newly registered firms (see Sect. 3.1), that is, firm birth within the neighborhood. The main advantage of using new firms is that they are not constrained by previous location decisions and sunk costs. Therefore, they provide better information on the role and magnitude of agglomeration effects than existing firms (Gómez-Antonio and Sweeney 2021). The variable is defined as

$$Y_{n,t} = \Sigma i_{n,t} \tag{1}$$

which denotes the sum of all firm births *i* in neighborhood *n* in year *t*. The uniform  $1 \times 1 \text{ km}^2$ —the neighborhood level—also implies the density per km<sup>2</sup>.

The second dependent variable is the number of firms relocating into the specific grids. This alternative specification allows to compare and benchmark the two avenues of growth.

The variable is defined as

$$Y_{n,t} = \Sigma j_{n,t} \tag{2}$$

which denotes the sum of all relocating j in neighborhood n in year t. The data are again drawn from the dataset presented in Sect. 3.1. Number of firms that moved into the grid, is arrived at from any address changes of the individual firms in a given year.

#### 4.2 Empirical setup

As the dependent variable is a count variable which is highly skewed (see Fig. 4), I use a Pseudo-Poisson-Maximum-Likelihood (PPML) model. The baseline model is presented in two specifications. First, I present an estimation that includes time- and city fixed effects. I aim to control for city-specific time-invariant characteristics and yearly increments, such as general trends in the industry or the economy at large. In a second specification, I use time- and grid fixed effects, where all time-and grid specific variation in the data is absorbed. Additionally, all observable and unobservable effects which might vary on grid- and time level are controlled for. This reduces the threat of an omitted variable bias. This technique allows valuable insights for policymakers at it shows what urban *changes* are relevant for new firms.

The following model will be estimated using PPML:

- -----

$$\begin{aligned} \ln(Y_{n,t}) &= \alpha + \ln(EDF_{n,t-1}) + \ln(EDF_{n*,t-1}) \\ &+ HigherEducation_{n,t} + HigherEducation_{n*,t} \\ &+ \operatorname{Research}_{n,t} + \operatorname{Research}_{n*,t} \\ &+ \ln(commercialbuilings_{n,t}) + \ln(commercialbuilings_{n*,t}) \\ &+ \ln(households_{n,t}) + \ln(priceindex_{n,t}) \\ &+ T_t + \gamma_j + \int_{n,t} \end{aligned}$$
(3)

The variable *EDG* (*existing digital firms*) is the cumulative number of digital firms present in the neighborhood (lagged by one year). This captures localization economics, that is, benefits derived from similar firms, for example by knowledge spillovers (see hypothesis 1). The variable enters the model on two spatial scales: the neighborhood level  $(1 \times 1 \text{ km}^2 \text{ grids } n)$  and first-order neighbors  $(3 \times 3 \text{ km}^2 \text{ grids } n^*)$ . Values for the first-order neighbors are calculated by summing the number of observations in the eight first-order neighbors.

The number of facilities of Higher Education Institutions as well as research institutes is included at both spatial levels in order to determine possible effects of knowledge dissemination from these institutions (see hypothesis 2). Further, the number of commercial buildings is used to capture urbanization economics, that is, a general benefit from other firms and a general economic environment (see hypothesis 3). In an average grid with 319 commercial buildings and 50 existing digital firms, there are 15% digital firms, assuming that one firm occupies one building. While in reality it is very likely that the overwhelming majority of commercial buildings are rented by multiple firms, the economic diversity of a neighborhood should be strongly correlated with urban diversity and human capital diversity. Again, all variables enter the model at the neighborhood level, as well as at the level of the first-order neighborhood in order to investigate the effects of distance on urbanization. The price index in the neighborhood captures a willingness to pay for agglomeration advantages. Similarly, the number of households is used as a control variable to capture overall density. As these effects are expected to be limited to the neighborhood, it only is controlled for at the *n* level. Finally,  $T_t$  is a time fixed effect,  $\gamma_i$  is a city (or grid in the alternative specification) fixed effect and  $\epsilon_{n,t}$  is the error term.

This empirical exercise is conducted twice in each specification of the model, i. firm birth as a dependent variable and ii. with relocating firms as described in Sect. 4.1. Such as in Manjón-Antolín and Arauzo-Carod (2011), the same regressors are used to determine whether firm birth and relocations are driven by the same factors (see hypothesis 4).

#### 5 Empirical results

The econometric results are presented in the following section. Columns (1) and (2) of Table 2 present the results of the empirical model that examines the neighborhood characteristics that determine firm birth. Columns (3) and (4) present the results of the estimations on the relocation of firms.

#### 5.1 Firm birth determinants

Column (1) of the analysis incorporates firm birth data for digital firms while accounting for time- and city-fixed effects, controlling for time-specific and city-specific variation in the data. The findings demonstrate significant clustering of new firms at the  $1 \times 1$  km<sup>2</sup> neighborhood level, with a notably higher rate of firm birth observed within grids where similar firms are already established. Moreover, a positive and statistically significant relationship is observed for the presence of similar firms in the first-order neighbors. The effect of firms within the very neighborhood (*n*) is greater than the coefficient for first-order neighbors (*n*\*), indicating an advantage for firms located in close proximity (within a kilometer) to their competitors. These results unequivocally suggest the presence of localized economies operating within neighborhoods of one square kilometer or smaller, which aligns with previous studies by Arzaghi and Henderson (2008),

Model: PPML				
Dep. Var.s:	Firm birth		Relocation	
Specification:	(1)	(2)	(3)	(4)
ln(EDF n (lag))	0.56***	-0.55***	0.56***	-0.61***
	(0.02)	(0.03)	(0.02)	(0.04)
ln(EDF n*(lag))	0.40***	0.13**	0.55***	0.27***
	(0.02)	(0.06)	(0.03)	(0.09)
Research Institutes n	0.00	0.37***	-0.02*	0.94***
	(0.01)	(0.12)	(0.01)	(0.19)
Research Institutes n*	$-0.01^{***}$	0.01	-0.03***	-0.08
	(0.00)	(0.04)	(0.01)	(0.06)
HEI n	-0.01	0.08	0.01	0.17*
	(0.01)	(0.08)	(0.01)	(0.09)
HEI n*	0.00	-0.01	0.00	0.12***
	(0.00)	(0.03)	(0.01)	(0.03)
ln(Commercial buildings) n	0.49***	1.65***	0.52***	2.09***
	(0.02)	(0.13)	(0.03)	(0.17)
ln(Commercial buildings) n*	-0.29***	-0.31	-0.33***	-0.91***
	(0.03)	(0.21)	(0.04)	(0.26)
ln(prices)	0.17***	0.29***	0.09	0.08
	(0.6)	(0.08)	(0.08)	(0.10)
ln(Households)	0.01	-0.59**	-0.13***	-1.42***
	(0.01)	(0.24)	(0.02)	(0.29)
Fixed effects				
Year	$\checkmark$	$\checkmark$	$\checkmark$	$\checkmark$
City	$\checkmark$		$\checkmark$	
Grid		$\checkmark$		$\checkmark$
Summary statistics				
Observations	12,726	12,726	12,726	12,726

Table 2 Location determinants for firm birth and relocation

For the regressors EDF  $n^*(lag)$ ; Commercial Buildings and Households the ln+1 is used. Standard errors in parentheses. Relocation refers to the number of relocating firms into the grid (In-Movers). Significance: p < 0.10, p < .05, p < .01

Andersson et al. (2019) as well as Lavoratori and Castellani (2021). The findings underscore the predominantly tacit nature of localized within-industry spillovers emphasizing the critical role of face-to-face interactions. Consequently, the innercity positioning of these clusters offers a valuable basis for evaluating the relevance and impact of other location factors. Based on these results, hypothesis (1) can be accepted. That is, *firm births in the digital industry occur in neighborhood environments where firms operating on a similar business model and knowledge stocks are already established, capturing localization economics.* 

Furthermore, specification (1) examines the impact of knowledge institutions, such as higher education institutions (HEIs) and research institutes, on the two spatial scales under investigation. Surprisingly, the findings reveal that the only significant coefficient is observed for research institutes within the first-order neighborhoods, and notably, it is negative. This unexpected result contradicts the hypothesis that newly established digital firms rely on tacit knowledge spillovers from HEIs and research institutes. Although Rammer et al. (2020) find innovative firms to locate close to knowledge institutions, I cannot find an effect in the quantity. A possible explanation for this could be the specific type of knowledge that is predominantly housed in universities. Previous research, such as Agasisti et al. (2019) and Malecki (2018), has demonstrated the crucial role of universities in entrepreneurial ecosystems. However, my findings indicate that knowledge transmission channels from universities to young firms may operate on a broader spatial scale than the  $1 \times 1$  km square. Alternatively, as HEI itself may contribute to the creation of the firm in the first place, young firms may require frequent academic input in their daily operations, but seek academic expertise when encountering specific development challenges. Daily business problems, on the other hand, are more likely to be resolved through interactions with firms that share similar characteristics, such as taxation issues or dynamic growth strategies (Colombo and Garcia 2022).

Further on in the case of the investigated German cities, there is no evidence of an effect of a possible overlap of student neighborhoods, at least not if it is assumed that students spend time there during the day and thus contribute to a certain milieu. In large German and European cities in general, it is an empirical challenge to identify such student neighborhoods. Unlike in the USA, students do not live on campus or in nearby student accommodations. For example, six percent of students in Hamburg and Berlin live in publicly provided student accommodation (Süddeutsche Zeitung 2010). Most students look for accommodation on the open market, which is often shared accommodation. Therefore, I do not see an effect in the sense of Florida (2002) or Hutton (2004). Accordingly, I reject hypothesis (2) that *universities contribute to firm birth at the neighborhood level*.

The coefficients on the number of commercial buildings in the neighborhood (*n*) and the first-order neighbors aim to control for general business density and reflect urbanization economies. The results show that an above average firm birth of digital firms occurs in neighborhoods with an above average density of commercial buildings. This indicates a positive effect of urbanization advantages in the neighborhood. This could mean that with a higher number of commercial buildings and office space, a greater variety of firms and human capital is present in the neighborhood, which leads to a more diverse spillover of ideas and knowledge applicable to the digital industry. This is in accordance with Jacobs (1969) idea of diversity contributing to economic growth. Astonishingly, the coefficient for the first-order neighbor is negative. This contradicts the results of Andersson et al. (2019), who find that urbanization effects operate at larger spatial scales than localization effects within cities. However, the results should be interpreted with caution as they do not perfectly control for diversity and neither building height nor available office space is explicitly controlled for due to lack of data.

The positive and significant coefficient on the price index as a control variable indicates that newly established firms, despite their relative youth and limited financial resources, tend to choose neighborhoods with above average rent prices. This finding strongly suggests a pronounced willingness to pay for agglomeration benefits. In other words, the benefits gained from co-locating with similar firms outweigh the higher costs associated with such locations. Hence, hypothesis (3) is *that a higher density of the built environment, that is localization economics, has a positive impact on the clustering of digital firms*. is accepted in line with the literature, for example Polèse (2014).

Upon further analysis of the variables related to the built environment and density, the number of households appears to have no significant influence. Roche (2020) argues that there are several advantages to a strongly connected environment in terms of knowledge exchange. Firstly, the abundance of potential contacts in such an environment greatly enhances the chances of serendipitous knowledge exchange. Secondly, a strongly connected environment facilitates better time management by minimizing travel distances between economic partners, formal knowledge centers, and social activity hubs. This reduction in travel costs not only lowers the expenses associated with interpersonal knowledge exchange, but also allows more time to be devoted to interaction (Roche 2020).

Column (2) presents the model with time and grid fixed effects. This means that the model controls not only for time and city variation, but also for spatial heterogeneity within each city at a more localized scale. By including grid fixed effects, the model captures all unobserved factors that are constant over time and differ across the  $1 \times 1$  km<sup>2</sup> grids within each city. The coefficients in this model reflect the effects of other variables on firm births within specific grid locations, taking into account within-grid variation over time. The interpretation of the coefficients in this model provides insights into how factors affect firm births within specific grid locations, taking into account both time- and grid-specific characteristics. That is, the coefficients explain the effects of changes within grids independently of general trends that affect all grids.

Regarding the clustering of firms within cities, the model shows a significantly negative coefficient for firm birth in the previous year. This indicates that an increase in the number of similar firms in the previous year (that is growth) is associated with an below average *increase* in the growth rate. This might first appear counter intuitive given the results from specification.

(1) However, it shows that increased competition among similar firms may pose challenges or barriers to entry for new firms within specific grid locations that hinders increased growth rates. This is not contradictory to specification (1) as it does not consider a general level effect. In other words, we learn from Specification (1) that in neighborhoods where many firms are already established, we can expect an above-average increase in new firms, leading to high growth rates. However, specification (2) then shows that although growth rates remain consistently high, the increase in the following year will not be above average. That means, there is still growth, but the year-on-year change in the growth rate is below average, despite an absolute increase. Interestingly, the results for first-order neighbors are positive, but on a relatively weak significance level. Hence, many similar firms in a wider

environment can stimulate growth on grid level. Regarding the effect of an increase in office buildings, the findings are consistent with those of specification (1). Specifically, an above-average increase in the density of office spaces corresponds to an increased number of firm births within the grid. However, an increase in the firstorder neighborhood has no effect on additional above average growth in firm birth activity in the neighborhood. In examining the changes in the knowledge infrastructure, the results obtained from the model incorporating grid and time fixed effects indicate that only the establishment of new research institutes has a significant and positive impact on increased firm births. However, it is important to interpret these findings cautiously due to the limited number of new research institutes observed during the study period, resulting in almost no variation in the data. When considering the built environment, an increase in the number of households acts as a deterrent. Intriguingly, neighborhoods that exhibit an above-average increase in prices also tend to experience an above-average growth in firm births. However, caution must be exercised in interpreting this result, as there may be a presence of reversed causality. That is, an increase in the number of firms-meaning an increase in spillover effects and small-scale agglomeration advantages such as increased productivity-contribute to increasing prices.

#### 5.2 Relocation determinants

When examining relocation patterns within the studied cities,<sup>6</sup> it becomes evident that there is a striking similarity between firm births and relocations, as hypothesized in hypothesis (4). Comparing columns (1) and (3) of the analysis, it can be seen that the spatial proximity to similar competitors plays an equally crucial role for both firm births and the decisions of young firms to relocate. This indicates that the presence of similar competitors in close proximity is equally important for firms establishing themselves and for those relocating. This result differs from the literature, as Manjón-Antolín and Arauzo-Carod (2011) and Holl (2004) find different requirements new and relocating firms, notably for manufacturing firms at the regional level.

Furthermore, the findings suggest that there is no evidence of crowding out from more expensive areas within the cities when it comes to relocations. The prices of the areas are not identified as a significant determinant of relocation decisions. This implies that firms are not necessarily deterred from relocating to more expensive areas within the cities, suggesting that other factors such as agglomeration benefits or access to specific resources might be more influential in determining relocation patterns. This is in line with the findings of Rossi and Dej (2020) as well as Kronenberg (2013), as it implies that digital firms do not necessarily adopt pure cost minimization, but choose locations where they can benefit from agglomeration benefits. Nevertheless, the results differ from manufacturing firms that relocate at the regional

<sup>&</sup>lt;sup>6</sup> The dependent variable is the number of firms that moved into the grid that is they changed their initial location in favor of the observed one. I do not consider firms that moved within the grid (although the results do not significantly differ, see Appendix A4).

level, as firms are expected to move from high-cost locations where they innovated toward lower cost locations from where they export (Foreman-Peck and Nicholls 2015; Duranton and Puga 2001). While Stam (2007) argues that relationships with social networks are particularly important in the early stages of a firm's life, while cost considerations become more important later, these results show that the availability of networks seems to be an important input for the young firms. Thus, this result is in line with Rossi and Dej (2020) and Kronenberg (2013) that firms do not necessarily adopt pure cost-minimization strategies when relocating.

Overall, the parallel patterns observed in firm births and relocations, as well as the lack of significance of price variables, shed light on the factors driving firm location choices and relocations within the studied cities. Regarding the formal knowledge infrastructure, the presence of research institutes in the neighborhood and even in the first-order neighbors demonstrates negative effects on firm births. This finding can be explained by two potential factors. First, it is possible that digital firms do not have a significant need for the knowledge available in research institutes. Alternatively, it could be that these firms do not require spatial proximity to access the knowledge offered by research institutes.

The results in column (4) exhibit similarities to those in column (2) concerning the local environment. This suggests that the local factors influencing firm relocations are consistent across the two models. However, when examining the impact of knowledge infrastructure, the findings in column (4) show that the presence of a new research institute can attract firm relocations. This contrasts with the results in column (3) where research institutes had a negative effect on firm births. It is important to exercise caution when interpreting this result, considering the limited variation in the data observed for new research institutes. Furthermore, the results indicate that the establishment of a new HEI can contribute to attracting relocating firms. This finding aligns with the results from the previous specifications, suggesting that there may be political effects at play supporting firm relocations into locations where new universities are established.

These results highlight the complex nature of the relationship between knowledge infrastructure and firm relocation. The contradictory results between different models and the potential influence of political factors emphasize the need for further investigation and careful interpretation of the findings. Overall, research showed that (informal) networks and ties to knowledge institutions are generally advantageous for entrepreneurial firms (Colombo and Garcia 2022; Löfsten et al. 2022), but the mere neighborhood investigation does not show the significant location effects, hinting that the networks are not tied to the specific neighborhoods (Table 3).

#### 5.3 Robustness

Several tests were carried out to assess the robustness of the results. To show that there is no multicolienearity, (Table 3) shows a correlation table of the used variables. Taking into account different factors within a city is crucial for understanding the dynamics of firms' location decisions. Among these factors, transport infrastructure and urban amenities have been identified in the literature as important

Table 3 Correlation table o	of the regr	essors										
	FB	M into <i>n</i>	Firms $n$ (lag)	firms $n^*$ (lag)	CommB n	CommB $n^*$	Households	prices	HEI <i>n</i>	HEI $n^*$	RIn	RI $n^*$
Firm Birth <i>n</i>	1	0.820	0.870	0.740	0.790	0.680	0.520	0.210	0.330	0.610	0.250	0.460
Movers into n	0.820	1	0.870	0.760	0.710	0.620	0.430	0.210	0.330	0.570	0.220	0.410
EDF n (lag)	0.870	0.870	1	0.820	0.800	0.690	0.510	0.270	0.350	0.610	0.250	0.470
EDF $n^*$ (lag)	0.740	0.760	0.820	1	0.690	0.840	0.530	0.340	0.370	0.700	0.280	0.560
Commercial buildings n	0.790	0.710	0.800	0.690	1	0.820	0.700	0.220	0.330	0.620	0.270	0.510
Commercial buildings $n^*$	0.680	0.620	0.690	0.840	0.820	1	0.660	0.290	0.380	0.710	0.310	0.610
Households	0.520	0.430	0.510	0.530	0.700	0.660	1	0.120	0.190	0.420	0.120	0.290
prices	0.210	0.210	0.270	0.340	0.220	0.290	0.120	1	0.073	0.160	0.080	0.200
HEI n	0.330	0.330	0.350	0.370	0.330	0.380	0.190	0.073	1	0.350	0.360	0.320
HEI $n^*$	0.610	0.570	0.610	0.700	0.620	0.710	0.420	0.160	0.350	1	0.310	0.660
Research Inst. n	0.250	0.220	0.250	0.280	0.270	0.310	0.120	0.080	0.360	0.310	1	0.320
Research Inst. $n^*$	0.460	0.410	0.470	0.560	0.510	0.610	0.290	0.200	0.320	0.660	0.320	1
FB= Firm Birth; M= Move	ers; Comr	nB= Comm	ercial Buildings	RI= Research Ir	nstitutes							

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Table 4Cross-sectionalregression for 2016

Model: PPML		
Dep. Var	Firm birth	Relocation
Specification:	(1)	(2)
ln(EDF n (lag))	0.58***(0.05)	0.63*** (0.06)
ln(EDF n*(lag))	0.40*** (0.07)	0.51*** (0.09)
Research Institutes n	0.03 (0.02)	0.02 (0.02)
Research Institutes n*	0.00 (0.01)	-0.02(0.01)
HEI n	-0.00	-0.00
	(0.02)	(0.03)
HEI n*	-0.02*	0.03**
	(0.01)	(0.01)
ln*(Commercial buildings) n	0.43***	0.39***
	(0.07)	(0.08)
ln*(Commercial buildings) n*	-0.27***	-0.28**
	(0.09)	(0.11)
ln(prices)	0.18	-0.14
	(0.13)	(0.15)
ln(Households)	-0.01	-0.12***
	(0.03)	(0.03)
Bus stops	0.00	0.00
	(0.00)	(0.00)
Motorway access	0.04**	0.00
	(0.02)	(0.03)
Local rail stations	0.00	-0.00
	(0.00)	(0.00)
Amenities	-0.00	-0.00**
	(0.00)	(0.00)
Summary statistics		
Observations	1818	1818

Standard errors in parentheses. Cross Section from 2016. For the regressors EDF  $n^*$  (lag); Commercial Buildings and Households the ln+1 is used. Relocation refers to the number of relocating firms into the grid (In-Movers)

Significance:\*p<0.10, \*\*p<.05, \*\*\*p<.01

indicators. Unfortunately, reliable data on these factors at a small spatial scale over time were not readily available. However, to partially address this limitation, data from OpenStreetMap (OSM) in 2018 were used to control for transportation infrastructure and amenities (proxied by bars and restaurants) in a cross-sectional regression analysis. The results of this analysis are presented in Table 4, as well as a correlation table of the newly introduced variables (Table 5). Notably, the coefficients in the baseline panel regression remain robust when the additional variables are included in the cross-sectional analysis. Interestingly, weakly significant coefficients

	FB	M into n	Firms n (lag)	firms $n^*(lag)$	Local rail stations	Motorway access	Bus stops	Amenities
Firm Birth <i>n</i>	1	0.840	0.920	0.800	0.300	0.022	0.320	0.760
Movers into n	0.840	1	0.860	0.760	0.260	0.003	0.290	0.670
EDF n (lag)	0.920	0.860	1	0.830	0.320	0.012	0.330	0.810
EDF $n^*(lag)$	0.800	0.760	0.830	1	0.320	0.038	0.350	0.720
Local Rail Stations	0.300	0.260	0.320	0.320	1	-0.017	0.180	0.370
Motorway Access	0.022	0.003	0.012	0.038	-0.017	1	0.110	0.009
Bus Stops	0.320	0.290	0.330	0.350	0.180	0.110	1	0.430
Amenities	0.760	0.670	0.810	0.720	0.370	0.009	0.430	1
FB= Firm Birth; M= N	Aovers; Com	mB= Commerc	ial Buildings; RI= F	cesearch Institutes				

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Table 6	Mover	within	grids
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Model: PPML		
Dep. Var.: Number of Movers within grid		
Specification	(1)	(2)
ln(EDF n (lag))	1.49***	1.13***
	(0.07)	(0.09)
$\ln(\text{EDF } n \text{ (lag)})$	0.15	-0.20
	(0.10)	(0.17)
Research Institutes n	0.02	-0.17
	(0.03)	(0.27)
Research Institutes <i>n</i> *	0.04***	-0.07
	(0.01)	(0.10)
HEI n	0.05	0.09
	(0.03)	(0.15)
HEI n*	-0.06***	-0.08*
	(0.02)	(0.05)
ln(Commercial buildings) n	0.15*	0.85**
	(0.09)	(0.35)
ln(Commercial buildings) n*	-0.29**	-1.24***
	(0.12)	(0.45)
ln(prices)	0.17	0.14
	(0.21)	(0.15)
ln(Households)	-0.05	-1.34**
	(0.04)	(0.56)
Fixed effects		
Year	$\checkmark$	✓
City	$\checkmark$	
Grid		V
Observations	12,726	12,726

Standard errors in parentheses. For the regressors EDF n\* (lag); Commercial Buildings and Households the ln + 1 is used. Significance: \*p < 0.10, \*\*p < .05, \*\*\*p < .01

are observed for motorway and light rail access in relation to business births, while no significant effects are found for local bars and restaurants. These findings are not consistent with the widely postulated notion of vibrant neighborhoods that facilitate face-to-face interactions as discussed in the literature (Hutton 2004; Roche 2020). None of the added variables are found to be significant in terms of business relocation).

In order to assess the robustness of the relocation measure, an additional regression analysis is conducted focusing on the number of relocations within the grids. The results of this analysis, presented in Table 6, provide insights into grid-specific factors that influence firms' decisions to stay within the same neighborhood when

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Model: PPML				
Dep. Var.s:	Firm birth		Relocation	
Specification:	(1)	(2)	(3)	(4)
ln(EDF n (lag))	0.67***	-0.24***	0.74***	-0.43***
	(0.03)	(0.06)	(0.05)	(0.10)
ln(EDF n*(lag))	0.38***	0.20	0.49***	0.38*
	(0.05)	(0.14)	(0.07)	(0.21)
Research Institutes n	0.01	0.38**	-0.01	1.06***
	(0.01)	(0.17)	(0.02)	(0.29)
Research Institutes n*	0.00	-0.01	$-0.02^{**}$	-0.05
	(0.01)	(0.06)	(0.01)	(0.08)
HEI n	-0.02	0.06	0.01	0.23
	(0.01)	(0.11)	(0.02)	(0.15)
HEIn n*	0.00	0.01	0.01	0.12**
	(0.01)	(0.04)	(0.01)	(0.05)
ln(Commercial buildings) n	0.29***	1.19***	0.24***	2.15***
	(0.04)	(0.25)	(0.05)	(0.36)
ln(Commercial buildings) n*	-0.37*** (0.06)	-0.10 (0.38)	-0.37*** (0.08)	-1.23** (0.52)
ln(prices)	0.06 (0.09)	0.22** (0.11)	-0.07 (0.12)	0.03 (0.15)
ln(Households)	-0.02 (0.02)	-0.48 (0.43)	$-0.10^{***}(0.03)$	-2.07*** (0.61)
Fixed effects				
Year	~	$\checkmark$	$\checkmark$	$\checkmark$
City	$\checkmark$		$\checkmark$	
Grid		v		$\checkmark$
Summary statistics				
Observations	8729	8729	8729	8729

Table 7 Only positive observations/intensive margin

Standard errors in parentheses. Relocation refers to the number of relocating firms into the grid (In-Movers). Significance: \*p < 0.10, \*\*p < .05, \*\*\*p < .01

they feel the need to relocate, potentially driven by changing office space requirements or other factors. The findings reveal that the presence of similar firms within the same neighborhood emerges as the most significant factor contributing to firms' decisions to remain in the vicinity. This underscores the importance of firm clustering and agglomeration effects in shaping relocation patterns within the studied neighborhoods.

Another technical concern relates to the substantial proportion of grids that did not record any instances of firm births within a given year, accounting for 69% of the total grids. To address this issue, an alternative empirical analysis was conducted by considering only those grids with digital firm birth throughout the observed period. The results of this analysis are presented in Table 7. These results focus specifically Model: PPML

Dep. Var.: Firmbirth in grids (ICT subsam	ple)	
Specification:	(1)	(2)
ln(ICT firms) (11ag) n	0.52***	-0.75***
	(0.02)	(0.04)
ln(ICT firms) (1lag) n*	0.41***	0.16**
	(0.03)	(0.06)
Research Institutes n	-0.02	0.53***
	(0.01)	(0.17)
Research Institutes n*	-0.02***	-0.04
	(0.01)	(0.06)
HEI n	0.01	0.05
	(0.01)	(0.10)
HEI n*	0.00	0.01
	(0.01)	(0.04)
ln(Commercial buildings) n	0.58***	1.52***
	(0.03)	(0.18)
ln(Commercial buildings) n*	-0.23***	0.20
	(0.04)	(0.27)
ln(prices)	0.39***	0.38***
	(0.08)	(0.10)
ln(Households)	0.02	-0.26
	(0.02)	(0.33)
Fixed effects		
Year	$\checkmark$	✓
City	$\checkmark$	
Grid		v
Observations	12,726	12,726

Table 8	Regression	on the subsam	ple of only	/ ICT firms
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For ICT(lag), the ln+1 is used. Standard errors in parentheses. Significance: p < 0.10, p < .05, p < .05, p < .01

on the intensive margin of firm birth and relocation, examining factors that contribute to firm growth in grids where firm birth has occurred previously. In essence, the intensive margin analysis provides valuable insights into the dynamics and adjustments within, shedding light on factors that influence further growth and development within these specific contexts. The results are robust to the baseline estimation. However, they show even stronger cluster effects, as the coefficient for the number of firms in the previous year is larger. Further, the effect from firms in the first-order neighborhoods is smaller compared to the baseline.

The underlying definition of digital firms in this paper differs from other papers in that it departs from standard industry classifications by including digital firms in other industries (for the reasons explained above). To ensure the efficiency of the sample, Table 8 presents the baseline regression results with a subsample of the data containing only firms registered in the ICT sector. The results are very similar to those from the baseline estimation. This suggests that including firms that rely on similar knowledge is an interesting avenue for future research, especially when discussing localization and urbanization issues at the microlevel.

# 6 Conclusion

This study simultaneously examines the birth and relocation patterns of young digital firms within cities. It shows that neighborhood-level spatial proximity to equally young firms with similar knowledge stocks is a significant explanatory factor for the evolution of clusters composed of new firms and young firms that relocate.

Overall, the econometric results shed light on the determinants of firm birth and relocation patterns within the cities studied. The analysis reveals significant clustering of firms at the  $1 \times 1$  km grid level, indicating a higher rate of firm births in grids where similar firms are already established. The presence of firms in firstorder neighbors also has a positive and statistically significant relationship with firm birth. These findings support the existence of localized economies operating within small-scale neighborhoods, consistent with Andersson et al. (2019). The results also suggest that neighborhoods with a higher density of commercial buildings, which are a proxy for general diversity, i.e., firms in general, are preferred for firm birth, while the number of households has no significant effect. Higher neighborhood rents are associated with higher growth in firm births, suggesting a willingness to pay for the benefits of agglomeration effects. The impact of knowledge institutions is mixed, with research institutes in the neighborhood and first-order neighbors having a negative effect on firm births, while the establishment of new higher education institutions attracts relocating firms. Policy makers should carefully assess the role of different knowledge institutions in promoting entrepreneurship and innovation. Collaboration between universities, research institutes, and industry can be encouraged to create a supportive ecosystem for digital firms.

The results on relocation patterns show similarities with firm birth patterns, with proximity to similar competitors playing a crucial role. Higher prices in areas do not deter relocation, suggesting the influence of other factors in relocation decisions. Policy makers should consider the dynamics of relocation in their urban planning and policy initiatives. Creating an environment that facilitates knowledge spillovers, networking opportunities and cooperation between firms is beneficial for firm growth in terms of firm births and relocations.

These findings contribute to our understanding of firm location choices and the role of knowledge infrastructure in driving firm births and relocations. Further investigation is warranted, considering the complex and potentially political dynamics underlying these relationships. For policy makers, the findings provide three main lines of action: First, a promotion of firm birth hubs for knowledge exchange. By actively facilitating the development of clusters, policymakers can enhance knowledge spillovers and collaboration among digital firms. Providing incentives or

creating dedicated spaces for these firms can contribute to the formation of localized economies and stimulate innovation. Second, targeted urban planning for firms and commercial density. Recognizing the preference for neighborhoods with a higher density of commercial buildings for firm establishment, tailored urban planning can create conducive environments that are also attractive for other firms to ensure diversity. This can include zoning regulations, tax incentives, and infrastructure development to support the growth of digital firms. Third, the lack of significance of firm birth close to Higher Education Institutions indicates a strategy for supporting knowledge institutions collaboration. Acknowledging the mixed impact of knowledge institutions on firm births, policymakers should actively encourage collaboration to maximize positive effects. Strengthening ties between academic and business communities can lead to a more supportive knowledge infrastructure, benefiting both entrepreneurship and innovation. Implementing such policies can contribute to the creation of dynamic and thriving ecosystems for the digital industry. In conclusion, the insights gained from Hamburg, Berlin, and Munich provide valuable knowledge about firm birth and relocation patterns in major cities. However, the transferability of these findings to other, even bigger cities with other dominant sectors, such as Frankfurt/Main, requires careful consideration. Future research should explore the applicability of these insights in different urban contexts, contributing to a more comprehensive understanding of the dynamics influencing digital firms across various city sizes.

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