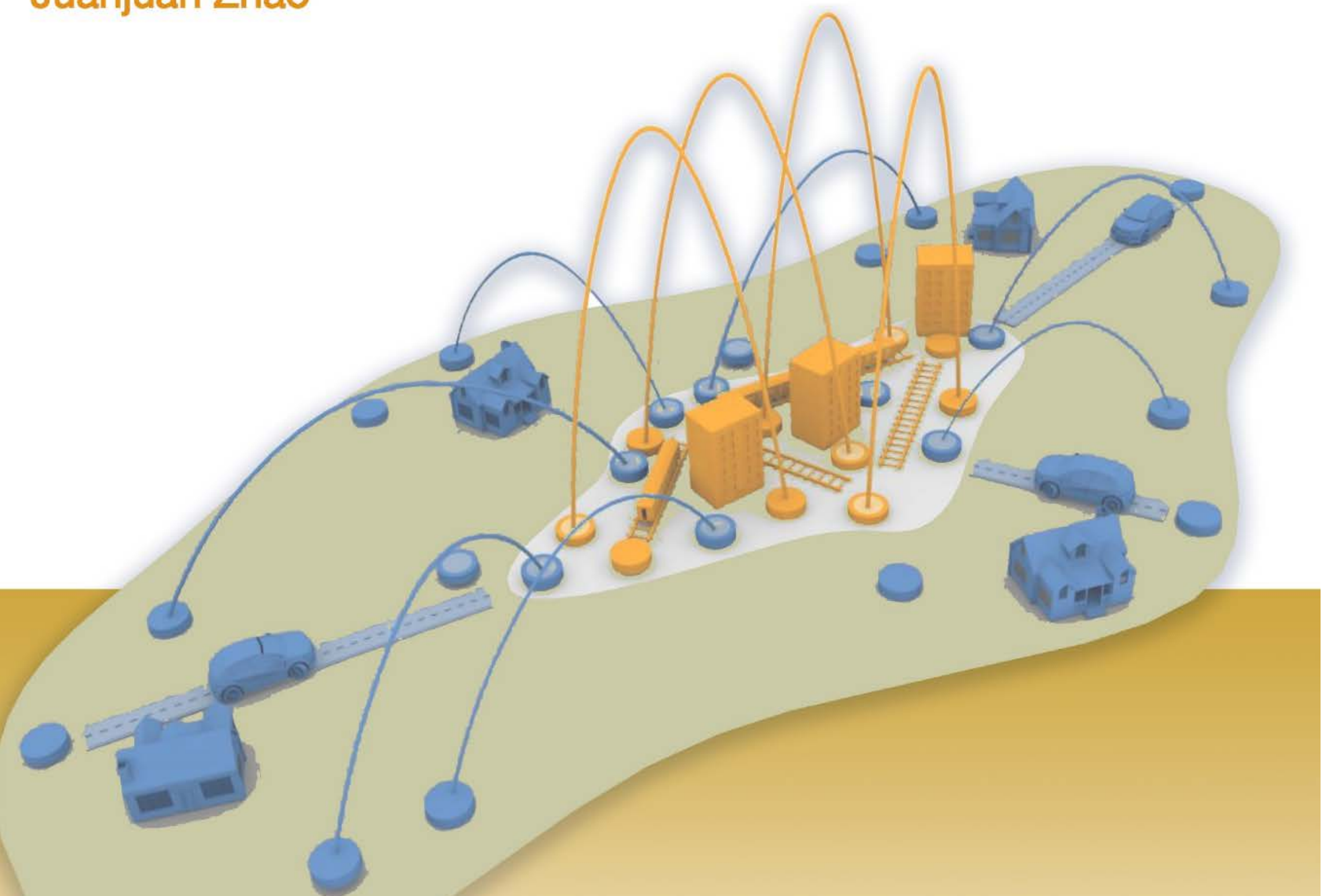
KNOWLEDGE BASE SHAPES USE OF SPACE:

Knowledge-workers' interrelated choices of residence, workplace and commute in the metropolitan region of Munich

PhD Thesis

Juanjuan Zhao



TECHNISCHEN UNIVERSITÄT MÜNCHEN

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Anhang I

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“Selecting housing is a process of knowing who we are and how our houses can express ourselves”

(Beamish et al., 2001, p. 21)

“We know what people want by observing what they have done”

(Storper and Manville, 2006, p. 1263).

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Summary

Knowledge workers, as individual agents who embody, transmit, exchange, create and exploit knowledge, function as innovation engines for knowledge-intensive firms, thus advancing the spatial development of metropolitan regions. To attract and retain knowledge workers in a region, it is necessary to have a better understanding of their spatial choices: specifically choice of residence, workplace, and commuting mode. Previous studies on knowledge workers' inter-regional migrations examined only the trade-offs between career perspective and quality of life. Such research viewed regions as homogeneous spaces and treated knowledge workers as a homogeneous population. This study further zooms into the metropolitan region of Munich and investigates the locational choices and mobility behaviors of knowledge workers. Furthermore, knowledge workers are differentiated into four subgroups according to employment sector (high-tech and advanced-producer-services/APS) and the knowledge typology (Analytical-synthetic-symbolic knowledge base) that they apply in jobs: namely analytical high-tech workers, synthetic high-tech workers, synthetic APS-workers, and symbolic APS-workers.

This empirical work was conducted in the metropolitan region of Munich, Germany. 7302 respondents that moved residences and/or changed jobs between 2011 and 2014 completed the online survey; 29% of this sample are the target group knowledge workers. The online survey gathers the information on individual previous residence/workplace, searched residential alternatives and selected current residence/workplace. Additionally, logistic regression analysis and spatial analysis are applied to understand the underlying trade-offs behind these interrelated spatial choices.

This study finds that symbolic APS-workers tend to reside in central areas and use public transport or active modes to commute. These workers are more likely to trade off cost or size of dwelling to reduce the commuting distance. In contrast, synthetic high-tech workers are found in relatively peripheral areas and more dependent on cars to reach their workplaces. These workers would trade off a longer commuting distance for a satisfying dwelling and/or job. The spatial choices of analytical high-tech workers and synthetic APS-workers are positioned between those of symbolic APS-workers and synthetic high-tech workers.

This study reaches three conclusions: Firstly, the features of the knowledge base are evident in the spatial choices of knowledge workers. Secondly, there is a consistency of characteristics among interrelated spaces surrounding residence, workplace, and the commute path of knowledge workers. Lastly, while the influence of the knowledge base has to be weighed against socio-demographic factors, different groups of knowledge workers clearly display distinct choices of residential location and commuting mode.

These insights allow urban planners and policy-makers to mitigate the increasing shortage of knowledge workers for innovative firms, even within large-scale urbanized regions. In addition, they may also provide insights helping to attract and retain knowledge workers. This will eventually impact the success in intra- and inter-regional competition for these qualified talents.

Zusammenfassung

Wissensarbeiter, als einzelne Agenten, die das Wissen verkörpern, übermitteln, austauschen, erschaffen und verwerten, funktionieren als Innovationsmotoren für wissensintensive Firmen und fördern die räumliche Entwicklung. Um Wissensarbeiter in einer Region anzuziehen und zu behalten, ein besseres Verständnis ihrer räumlichen Entscheidungen ist notwendig: spezifische Entscheidungen in Bezug auf den Wohnsitze, den Arbeitsplatz und das Verkehrsmittel für den Pendelweg. Bisherige Studien zu ihrer interregionalen Migration untersuchten nur die Kompromisse zwischen Karriereperspektive und Lebensqualität. Solche Untersuchungen betrachteten Regionen als homogenen Raum und behandelten Wissensarbeiter als homogene Bevölkerung. Diese Studie zoomt weiter in die Region hinein und untersucht die Standortwahl und das Mobilitätsverhalten von Wissensarbeitern. Darüber hinaus unterscheiden sich Wissensarbeiter durch den Beschäftigungssektor (Hightech- und Fortgeschrittene-Produzenten-Dienstleistungen / APS) und die Wissenstypologie (Analytisch-synthetisch-symbolische Wissensbasis), die sie am Arbeitsplatz anwenden, in vier Untergruppen: nämlich analytische Hightech-, synthetische Hightech-, synthetische APS- und symbolische APS- Wissensarbeiter.

Diese empirische Arbeit ist in der Metropolregion München in Deutschland durchgeführt. 7302 Befragte, die ihren Wohnsitz und/oder Arbeitsplätze zwischen 2011 und 2014 gewechselt haben, haben an der Online-Umfrage teilgenommen, 29% dieser Stichprobe entsprechen Zielgruppe Wissensarbeiter. Die Online-Umfrage enthält Informationen über der individuellen vorherigen Wohnsitz / Arbeitsplatz, gesuchte Wohnalternativen und den ausgewählten aktuellen Wohnsitz / Arbeitsplatz. Darüber hinaus werden die logistische Regressionsanalyse und die räumliche Analyse angewendet, um die zugrunde liegenden Kompromisse hinter diesen zusammenhängenden räumlichen Entscheidungen zu verstehen.

Diese Studie stellt fest, dass symbolische APS-Wissensarbeiter dazu neigen, in zentraler Lage zu wohnen und mit öffentlichen oder nichtmotorisierten Verkehrsmitteln zu pendeln. Sie sind eher zu einem Kompromiss in Bezug auf Koste oder Größe der Wohnung bereit, um die Pendelstrecke zu verringern. Im Gegensatz dazu sind synthetische Hightech-Wissensarbeiter in relativ peripherer Lage zu finden und das Erreichen ihres Arbeitsplatzes hängen eher von der Nutzung des Autos ab. Diese Wissensarbeiter würden eine längere Pendelstrecke für eine

gute Wohnung und / oder einen befriedigenden Job akzeptieren. Die räumlichen Entscheidungen der analytischen Hightech- Wissensarbeiter und der synthetischen APS-Wissensarbeiter liegen zwischen denen der symbolischen APS- und synthetischen Hightech-Wissensarbeiter.

Aus dieser Studie ergeben sich drei Schlussfolgerungen: Erstens sind die Merkmale der Wissensbasis im Hinblick auf die räumlichen Entscheidungen der Wissensarbeiter offensichtlich. Zweitens gibt es eine Konsistenz von Merkmalen zwischen zusammenhängenden Räumen, die den Wohnsitz, den Arbeitsplatz, sowie den Pendelweg den Wissensarbeitern umgeben. Zu Letzt muss der Einfluss der Wissensbasis gegen soziodemographische Faktoren abgewogen werden, trotzdem treffen verschiedene Gruppen von Wissensarbeitern deutlich unterschiedliche Entscheidungen bezüglich des Wohnortes und des Verkehrsmittel für den Pendelweg.

Diese Erkenntnisse erlauben es, den zunehmenden Mangel an Wissensarbeitern für innovative Unternehmen auch in großflächigen urbanisierten Regionen zu verringern. Darüber hinaus können sie auch Einblicke für Stadtplaner und Politiker in die Anziehungskraft einer Region und den Bleibewunsch von Wissensarbeiter geben. Dies wird letztlich zum Erfolg im inner- und interregionalen Wettbewerb um diese qualifizierten Talente beitragen.

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List of Abbreviations

APS	Advanced-Producer-Services
BFS	Bundesamt für Statistik
BBSR	Bundesinstitut für Bau-, Stadt- und Raumforschung
ICT	Information and communication technology
IT	Information Technology
IMU	Institut für Medienforschung und Urbanistik
KW	Knowledge workers
MMR	Munich metropolitan region
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
SQM	Square meter
WZ	Wirtschaftzweige
GIS	Geographical Information System

Part I RESEARCH BACKGROUND

1 Introduction

This chapter will firstly establish the significance of the research topic in the age of the knowledge economy. Secondly, the current state of research as well as the research gap will be elaborated. This is followed by the specific research questions aiming to contribute knowledge to filling this gap. Lastly, the outline of the dissertation will be presented.

1.1 Knowledge creation is crucial in the age of the knowledge economy

The arrival of the age of the knowledge-economy

The knowledge-based economy is increasingly important against the background of globalization and the tendencies to deregulation and liberalization in the wake of the transition of the global economy from industrial to a post-industrial economic structure (Piore and Sabel 1984; Hall and Castells 1994; Florida 2002b; Currid and Connolly 2008; Archibugi and Lundvall 2001). The knowledge focus is the third wave of human socio-economic development following agricultural and industrial wave and wealth is based upon the ability to use the embodied knowledge to create or improve goods and services in the knowledge age (Savage 1996). Knowledge, as a source of economic production, tends to grow indefinitely in contrast to depletion-subject material resources (Storper and Scott 2009: 148). In addition, knowledge is extremely leaky, can be re-used, combined and recombined in all kinds of ways (Storper and Scott 2009: 148). Therefore, knowledge is becoming the most valuable production factor in the knowledge economy.

Constant creation of knowledge contributes to the competiveness

Nevertheless, knowledge itself does not contribute to the competiveness of a region. Instead, the strategic combination and constant creation of new knowledge through interaction processes, mainly in innovation, know-how, human networks, and labor markets, are essential to sustaining competitive advantages and drive development (Lüthi 2011: 21; Vissers and Dankbaar 2013). “Action of knowledge upon knowledge itself ”(Castells 1996: 27) and “the exploitation of new knowledge in order to create more new knowledge” (Cooke et al. 2007: 51) are typical features of knowledge economies. Overall, knowledge creation lies at the center of economic growth, the innovation in products, processes or organizations, as well as fueling and speeding up economic development (Cooke et al. 2007). The knowledge economy is unevenly distributed in space and specific places monopolize knowledge. Specific regions such as Silicon Valley, Boston, Cambridge or Munich offer trusted contexts for knowledge exchange and creation, thus are relatively advanced in knowledge economies (Cooke et al. 2007).

1.2 Localization of knowledge workers is essential for regional development

Human capital remains important in spite of technological advance

With advancements in technology, there is a shift from routine or manual tasks towards non-routine analytical and interactive tasks. This has led to an increasing demand for highly skilled and highly qualified individual managers to plan, and highly trained individual technicians to design new tools and products, and maintain and direct them afterwards (Drucker 1954; Autor, Levy and Murnane 2003). Accordingly, within large metropolitan areas, there is an expansion of occupations that call for sophisticated forms of personal interaction (mentoring and negotiating) or highly skilled forms of data manipulation (synthesizing and coordinating) (Scott 2008).

Knowledge workers, as basic units of interactions are key for knowledge creation and innovation

Knowledge economies increasingly demand the cognitive skills of human capital and their ability to empower and exploit their embodied knowledge (Storper and Scott 2009: 163). Knowledge is a cognitive capacity of individuals that embody it and empower the action (Cooke et al. 2007), which differentiates it distinctly from information. Individual agents (knowledge workers and knowledge-intensive firms) are essential to fully exploit knowledge and create value. Secondly, knowledge is relational in essence and the meaning of knowledge only exists when people are transmitting or exploiting it rather than standing alone (Bathelt and Glückler 2011: 64-71). The generation of innovation is a cumulative process in which economic actors benefit and learn through communication and interaction with other actors (Graf 2006). Although both knowledge-intensive firms and knowledge workers may be categorized as individual agents of knowledge creation, knowledge-intensive firms do not interact directly. Instead, face-to-face interaction is only possible at the personal level and it is individuals that execute or operationalize the interactions that firms require (Vissers and Dankbaar 2013: 709).

'Localization' of knowledge workers generates knowledge spillover and contributes to development

Cities with endowments of abstract and analytical skills are more likely achieve economic growth (Berger and Frey 2016). The key to regional growth as well as resurgence lies in endowments of highly educated people and productive people (Glaeser 1998: 1251; Florida 2003; Storper and Manville 2006). The flows of knowledge, either spillovers or traded services, highly depend on where knowledge workers move to and locate (Breschi and Lissoni 2003). Once knowledge workers enter a region and remain there subsequently, their knowledge will be diffused through local buzz (Almeida and Kogut 1999; Miguelez and Moreno 2014: 55). Accordingly, places that are home to a large concentration of knowledge workers tend to rank highly as centers of innovation and high-technology and grow faster owing to the innovative energies that those individuals bring with them (Storper and Scott 2009: 148; Florida 2003). The Munich region's competitiveness is largely owing to its largest share of highly qualified workers (Hafner, Heinritz, et al. 2008: 11).Boston's ability to recover its economy is also due to the supply of skilled labor (Glaeser 2005: 122). Knowledge workers as well skilled talents have become the dominant factor in regional development.

1.3 Understanding location preferences of knowledge workers also facilitates spatial planning and location of knowledge-intensive firms

Understanding and predicting the spatial pattern

Spatial structure functions not only as the precondition for people's choices, but also the result of their mobility in terms of housing and job mobility. The built environment is the most obvious manifestation of socially constructed entities (Næss 2016: 2). Cities are actually accumulated spatial entities resulting from the aggregated preferences of previous generations, since "the physical results of people's past preferences for housing last longer than do the people themselves" (Storper and Manville 2006: 1267). Current residential choices are conditioned to some extent by earlier choices (Storper and Manville 2006: 1262). Analogously, the residential locations driven by people's current preferences for housing will last longer and will influence future spatial pattern. To summarize, residents in a region modify as well as restrict spatial development, via their involvement in residential space differentiation. Accordingly, studying the residential choice of knowledge workers helps to better understand, predict, as well as facilitate future spatial development.

Facilitating the location strategy of knowledge-intensive firms

Given that highly qualified individuals are now a key factor in production, knowledge-intensive firms have become increasingly dependent on the competencies of the labor force and are increasingly making location choices according to where there is a large pool of qualified labor (Frenkel 2012: 246; Florida and Gates 2001). In addition, the absolute causal relation between workplace location to residence location (the so-called 'people follow jobs') has been challenged theoretically and empirically (Steinnes 1982; Waddell et al. 2007), since the assumption that the arrival rate of jobs is relatively lower compared to housing does not always hold true. More and more project-oriented employments are appearing nowadays and individual attachment to the current workplace is diminishing in importance. Hence, many knowledge workers choose their residence simultaneously or even prior to the choice of job location. To summarize, as the scenario where "firms follow skilled people and skilled people go to places with amenities that suit them" is increasingly the case (Storper and Manville 2006: 1251). Thus, knowing the preferences and behaviors of each group of knowledge workers is important in guiding the location choices of knowledge-intensive firms in a region (Storper and Venables 2004).

1.4 Research gaps exist in current studies on spatially-related choices of knowledge workers

1.4.1 Education level is not the determinant characteristic of knowledge workers

Individuals with high cognitive skills who fulfill important management functions are key agents deserving further scrutiny. It is well worth examining the underlying stick forces that attract these workers to settle in a region, develop local networks, and in turn generate spillover effects in the region (Cooke 2014). Human capital theory regard the formal education as a proxy to depict qualified workers (Johnes 1993; Cohn 1980). However, formal qualification level does not necessarily accurately reflect cognitive skills (Glaeser et al. 2004; Becker 1993). An individual may have the best of knowledge in mind due to the high level of formal education, but, in the words of Cook and Brown (1999), this knowledge is inert unless it is used in practice (Cook and Brown 1999). Therefore, the practice of the knowledge such as the occupation should be also included. A functional conceptualization of these talented individuals is therefore necessary in the effective selection of knowledge workers.

1.4.2 Existing inconclusive findings imply the heterogeneity of knowledge workers

Existing studies on driving forces in the spatial processes determining knowledge workers' spatial choices are inconclusive so far. On the one hand, knowledge workers revitalize and regenerate urban core areas, contributing to the concentration process (Lee, Burfitt and Tice 2009; Kunzmann 2009). On the other hand, they encourage urban sprawl and contribute to the de-concentration process (Felsenstein 2002). The variety of their spatial choices is related to the different weight accorded by different groups of knowledge workers to classical and amenity factors, their different conceptualization of residential amenities, as well as different tolerances of the commute distance or importance of housing-job proximity. The following sections will elaborate on these aspects in detail.

Classical factors vs. amenity factors in residential location choice

Some studies reveal that classical factors such as housing costs and sizes, as well as accessibility to work are still important considerations for knowledge workers. Lawton, Murphy and Redmond (2013) confirmed that cost of dwelling, distance to work and size of dwelling are still prominent in the residential location choices of knowledge workers in Dublin (Lawton, Murphy and Redmond 2013). Furthermore, Frenkel, Bendit and Kaplan (2013b) concluded that municipal socio-economic level, housing affordability and commuting time are the most important factors for knowledge workers' residential choice in the Tel-Aviv Metropolitan region (Frenkel, Bendit and Kaplan 2013b), which is also consistent with the finding for the Munich region (Hafner, Heinritz, et al. 2008).

Different types of residential amenities

The emergent amenity-driven location studies hold that residential amenities are actually more significant than traditional factors among knowledge workers. The definition of residential amenities varies. On the one hand, the desire for 'vibrant', 'bohemian' neighborhoods forms a focal point of the amenity preferences in Florida's thesis of the 'creative class'(Florida 2002b). The 'creative class' account for 30 to 40 or even 45 percent of the employment in most developed OECD countries (Asheim and Hansen 2009: 429). These workers value an urban image of an active street scene of coffee shops and bars in a historic or 'bohemian' urban area, as well as having a greater tolerance towards immigration and integration (Haisch and Klöpper 2015; Florida 2002b). On the other hand, Glaeser (2004) hold the differing and even opposite view that talented individuals seek amenities in suburbs (Glaeser 2004). Furthermore, van Oort, Weterings and Verlinde (2003) confirm both strands of findings that residential amenities, including accessibility to a city center that provides urban services, as well as public spaces such as parks and plazas, are both important for residential choices among Information and communications technology (ICT) workers (van Oort, Weterings and Verlinde 2003).

Contradicting responses to spatial proximity: co-location hypothesis vs. commute tolerance

In addition, there is no agreement reached upon individuals' preference for spatial proximity between residence and workplace. On the one hand, the co-location hypothesis argues that households' ability to minimize commuting distance via joint housing and job location is underestimated (Korsu 2012; Eggers and Moumen 2005). Rational locators will adjust their residential or workplace location to minimize their commute distance. On the other hand, the theory of commuting tolerance argues that people do have certain tolerances for commuting and too much value has been attached to the housing-job connection (Horner 2004). To this end, the difference of tolerance for commuting among different groups needs more careful investigation (Korsu 2012; Einig and Pütz 2007). This would apply no less to knowledge workers than to more general labor groupings.

To summarize, the implied heterogeneity of knowledge workers indicates the necessity to further disaggregate this group and examine their distinct spatial behaviors especially related to their location preference and choice, as well as the role of commute in their decision-making process.

Knowledge workers are heterogeneous, further categorization is necessary

1.4.3 Inter-regional migration studies do not explain fully intra-regional residential location choice

Regarding the place of living and working, people in general face trade-offs between living costs, wages and amenities. Even though consumer tastes (e.g. the preference for certain urban amenities) are taken into account in making individual residential choices, the primary or pivotal factor is in most cases income and employment prospects. In other words, consumer tastes follow income, rather than determining individual location choices (Storper and Manville 2006: 1253). This mechanism of decision-making mainly applies to inter-regional migration. Existing studies on knowledge workers' location choices tend to focus on their inter-regional migration, which treat regions as homogeneous entities and are limited to the statistical relationship between the general characteristics of the region and number of knowledge workers (Darchen and Tremblay 2010; Florida et al. 2012). They report that large cities attract more knowledge workers, since they offer better employment opportunities, better access to all kinds of services, and greater urban diversity (Florida et al. 2012; Darchen and Tremblay 2010; Yigitcanlar and Martinez-Fernandez 2007; Straubhaar 2000).

Much focus on inter-regional migration

Nevertheless, few research endeavors have investigated knowledge workers' more specific locational preferences, once they have decided to settle in a region or upgrade their space within the same region. Regarding intra-regional location choices, minor differences among city districts become apparent and must be taken into consideration. As Storper and Manville (2006) summarizes, "regions or cities that are statistically diverse are often quite segregated at local scales, be it the neighborhood or even the block level" (Storper and Manville 2006: 1256). Knowledge workers would tentatively land in or select a small spatial tract within a region. The aforementioned mechanism of decision-making

Intra-regional location choice considers more specific location factors applicable to inter-regional migration might therefore not be particularly straightforward. Despite individuals moving to the region for the income level or prospects offered by the job, they still face many residential alternatives located within a number of jurisdictions in the region. This being the case, the quality of space becomes more important compared to the job-related considerations (Yigitcanlar 2010; Kim, Horner and Marans 2005). Individuals will also consider many other specific location aspects such as the distance to public transport stations, and the availability of cultural activities (Thierstein et al. 2013). For instance, individuals who value the aesthetic appeal of the city highly and prefer to walk or cycling might choose a residence located in the city center (Storper and Manville 2006: 1258).

1.5 Three research questions to address the interrelated choices of residence, workplace and commute of knowledge workers

As elaborated previously, only when knowledge workers remain within a region for a long period are knowledge externalities generated, which contributes to the competiveness of the region. In order to better attract and retain knowledge workers within a region, it is necessary to have a thorough understanding of their fundamental spatially-related choices as a resident, an employee, as well as a leisure consumer. Residence and workplace locations are the major spatial anchors for a worker (Neutens, Schwanen and Witlox 2011). Furthermore, the area between the location of home and work defines the basic territory of an individual (Levinson and Wu 2005: 188). Individuals tend to plan their other activities relative to their residence and workplace, as well as along the commute path (Redmond and Mokhtarian 2001). Specifically, this study aims to answer the following three specific questions:

First, how can knowledge workers be differentiated into subgroups, given that they are not a homogeneous group?

Second, how do knowledge workers optimize the use of space, specifically: interrelated choices of residence, workplace and commute behavior in a metropolitan region?

Third, what kind of trade-offs do knowledge workers have to make in these spatially-related choices?

1.6 Outline of the dissertation

Part II introduces existing theoretical background as well as the process of developing the research hypotheses. Specifically, Chapter 2 provides an overview of the existing theories and empirical work on spatially-related choices including choice of residential location, workplace location, and commute mode. Chapter 3 introduces the perspective of knowledge typology (Analytical-Synthetic-Symbolic knowledge base) and its relation to spatial proximity as well as the orientation towards the local external environment. At the end of Chapter 3, the spatial patterns of knowledge-intensive firms with different types of interactions are discussed. Chapter 4 firstly presents the linkage between spatial structure and the underlying opportunities for interactive learning, which leads to one of the underlying assumptions of the study, namely that individual spatially-related behavior could reflect their orientation towards encounters with other individuals. Following this, interpretations of knowledge workers' choice of residence and commute of are offered. This second part ends with three specific research hypotheses.

Part III firstly introduces the research design, including the target group (knowledge workers and its categorization), the research area (the metropolitan region of Munich and its spatial-functional structure). It then continues with the introduction of research data and the explanation of specific methods of analysis that are applied in the research.

Part IV presents the research findings in three chapters, which correspond to the three research hypotheses. Chapter 6 describes the spatial concentration or de-concentration processes of knowledge workers in terms of their residential location choices. Chapter 7 elaborates the underlying trade-off processes and the revealed preferences for certain spatial attributes within residential location choices. Chapter 8 focuses on the commute mode choices of knowledge workers.

Part V contains discussion and conclusions. Chapter 9 firstly discusses the implications of the key findings in part IV individually. After this, it focuses on the interrelation between residential, workplace and commute choices and discusses how knowledge workers optimize the usage of space. Chapter 10 synthesizes all the key findings and discussion points, and draws the main conclusions. In addition, some general learnings acquired during the investigation of the research questions are also summarized. The major limitations as well as suggested directions for improving and deepening further study in this area are also mentioned in the future outlook at the end of the dissertation.

Part II THEORETICAL BACKGROUND

2 Use of space: interrelated spatially-related choices of residence, workplace, and commute

This chapter will begin with an introduction to the comprehensive conceptual framework that guides the theoretical literature review as well as the subsequent empirical work. The remaining sections of this chapter focus firstly on the existing theories and empirical findings on choices of residence and workplace. This is followed by a separate elaboration of the role of commute distance and time in location choices, which links to the choices of residence and workplace, as well as connecting to the choice of commute mode in the next section. In addition, the influence of individual characteristics on these spatially-related choices will be mentioned at the end of each section.

2.1 Comprehensive conceptual framework: decision-maker, knowledge-typology perspective, and spatially-related choices

The comprehensive framework for studying knowledge workers' spatially-related choices is shown in Figure 1. This study focuses on the use of space of knowledge workers, which involves bundled consideration of residence, workplace and mobility behavior (Tran et al. 2016; Anas 1981). Residential move and job change are interrelated (Clark, Huang and Withers 2003; Shi et al. 2013), which is conditional on commuting cost in terms of time and distance (van Ommeren, Rietveld and Nijkamp 1999). Spatially-related choices are classified into long-, medium- and short-term. Long-term choices include residential, job location, and commuting distance; medium-term choices refer to mobility resource, including car ownership and public transport travel pass (Van Acker and Witlox 2010). Commuting mode belongs to short-term choices. There are two groups of factors chiefly influencing knowledge workers' interrelated choices of residence, workplace and commute. The first group is the conventional perspective, namely the characteristics of individual decision-makers. It refers to socio-demographics including gender, household type, education level and the income level, as well as mobility preferences such as travel-related locational preference, i.e., the preference for car-friendly, public transport-friendly, or cycling/walking-friendly location. The second group refers to a new perspective of knowledge typology. This chapter will focus on how conventional factors influence these spatially-related choices. The linkage between the features of each knowledge base and spatially-related choices of knowledge workers will be discussed in detail in the second and third chapter of the theoretical background.

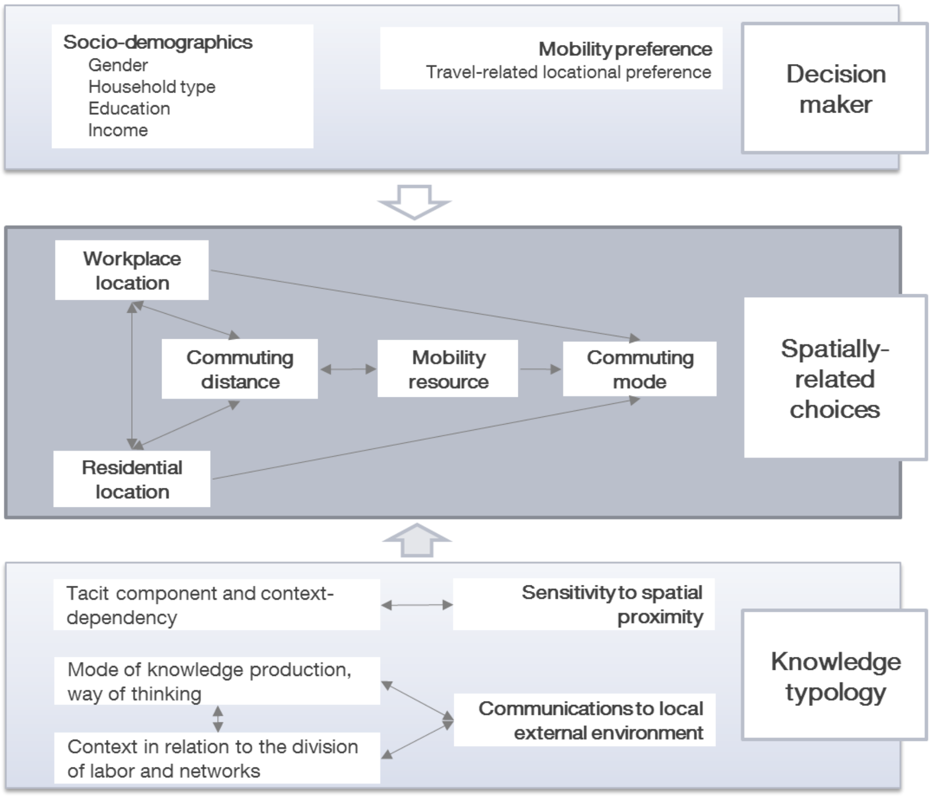


Figure 1. A comprehensive framework consists of spatially-related choices and its relation to the characteristics of the decision maker and knowledge typology.

2.2 Residential choice and its relation to workplace location

This section will begin with the introduction of bounded rationality in individual decision-making, especially in residential choice. It goes on to introduce different theories or approaches to understanding residential choice. Following this, the role of workplace location in the residential choice is also discussed. Finally, this section will mention the association between socio-demographic situation and residential choices.

2.2.1 Bounded rationality in individual decision-making

Theoretically, rational consumers maximize utility in decision-making

In general, "people make decisions to advance their self-interests" (McFadden 2002: 4). Individuals make decisions that maximize their total utility subject to budget and time constraints as well as their demands (Handy 2005). Classical economically rational consumers will weigh the attributes of each available residential alternative including the accessibility of the workplace, shopping and schools, quality of neighborhood life, the availability of public services, cost of housing, characteristics of the dwelling, and eventually select the alternative that maximizes the total composite utility (McFadden 1978). During this process, individuals balance the associated costs and benefits of each available location alternative, whose costs are measured in monetary and time terms, and the benefits are measured in proximity, space and other satisfied preferences (Levinson and Kumar 1994: 330).

In most cases, Individual decision-making is bounded rationality

However, behavioral theories admit that in most cases, decision-making is not perfectly informed when individuals optimize the overall utility of choices regarding the housing market, labor market, services, mobility options and time allocation. For instance, each individual's knowledge about the city they reside in is geographically specific. That is, the individual has the largest amount of knowledge regarding the immediate adjacent neighborhood and this decays with the increase of the distance from it (Adams 1969). Incomplete information about alternatives and individuals' restricted ability to process information is termed bounded rationality (Simon 2000). In most cases, individuals tend to choose a location with a higher utility currently or in the near future, compared to other places that are conspicuous to them (Wolpert 1965: 162). The utility they assess is strongly related to the current situation of the action space, namely the perceived state of their environment (Wolpert 1965: 163). For instance, the utility assigned to a place differs between individuals who participate frequently in cultural activities and those who participate rarely in such activities (Florida 2002b).

2.2.2 Theories and approaches in residential choice

Residential choice considers attributes on three spatial scales

Residence is a good with multi-dimensional attributes. Individuals may consider three categories of attributes in residential choice. Firstly, an individual can consider the micro-scale dwelling attributes including the specific size, tenure, cost, type, as well as the age of the dwelling. Secondly, individuals can consider meso-scale attributes, including the community environment, such as the quietness, greenery, socio-economic status, as well as the accessibility to retail outlets and services, transit stations and schools. Individuals are actually paying for the access that the neighborhood offers them to other people (Florida 2015) as well as the optimal profiles of the neighborhood or the vicinity (Kalisch 2014). Thirdly, they can consider the macro-scale relative location including the distance to city center, workplace (Horner 2004) or a particular industry (Florida 2015), as well as to their social networks (Schirmer, van Eggermond and Axhausen 2014). "Households search for residences in a geographically focused way" (Rodriguez and Rogers 2014: 537; Huff 1986: 209), for instance space surrounding the previous residence and individual main activity locations (Johnston 1972: 199). To summarize, individual households not only want to possess the amenities at and near the residence, but also try to maximize the proximity to important activity nodes including workplace, social networks and services. There are various theories or approaches to accounting for the decision-making process on the residential choices. These will be introduced in the following paragraphs.

Theory of access-space trade-off in residential location

The classical residential location theory of access-space trade-off states that people make trade-offs between housing costs and transport costs in their residential location choices (Alonso 1964; Muth 1969; Evans 1973; Romanos and Romanos 1976; Thrall 1987). As the speed of increasing population is faster than the speed of space expansion in the metropolitan region, this might lead to an increasing proportion of people who will trade off the commute time for additional space (Levinson and Wu 2005: 199). This resonates with the finding of Scheiner (2006) that in places where there is a lack of affordable housing, people usually trade off transport costs for better housing and seek more distant but lower cost locations (Scheiner 2006: 290). This simplified hypothesis has been challenged, since residential location choice is multi-faceted (Hamnett and Williams 1980; Phe and Wakely 2000). Housing not only brings accessibility, it is also freighted with further concerns: an independent physical and social environment, or symbols of social standing (Phe and Wakely 2000). When choosing a house, individual households are not only choosing an attractive area to live, but also a neighborhood that is consistent with their social and economic status.

Theory of status-quality trade-off in residential location

This links to the second residential location theory of status-quality trade-off (Phe and Wakely 2000). According to this theory, people make trade-offs between the status of residence and the quality of housing. Housing status measures the social desirability attached to housing as a particular locality. The 'status' not only refers to the proximity to work but also other important poles such as education or cultural centers. It could represent the wealth, culture, environment quality, etc. The term 'quality' here means the physical measurable housing conditions including size, facilities, typology, and age of the housing. It is analogous to the space of the housing in the previous trade-off theory. Instead of exclusively focusing on transportation and housing, the status-quality trade-off also considers the status of the residence and the potential reach of major activity nodes (Phe and Wakely 2000).

Theory of household-centered 'nestling' in residential location.

The third theory, the household-centered nestling approach, further elaborates on the current and potential accessibility to spatial locations of key activities. 'Nestling' refers to households' balancing or stabilizing residential location in relation to geographical locations of other activity nodes (Figure 2) (Olatubara 1998: 65). These activity nodes are daily spatial orientations like location of workplace, social networks, or leisure activities (Scheiner 2006: 290). Each household constitutes a nucleus of a micro-activity systems, which aggregately form the complex urban spatial pattern (Olatubara 1998). Correspondingly, Saxena and Mokhtarian (1997) report that high-income individuals with greater commute tolerance regard their residences as “a sally port within their action space” (van Oort, Weterings and Verlinde 2003: 517; Saxena and Mokhtarian 1997). Following this approach, the decision of a household to change residential situation depends on not only the income and the aspired to change in lifecycle, but also planned change of the activity nodes including change of the job and locations of other major daily activities.

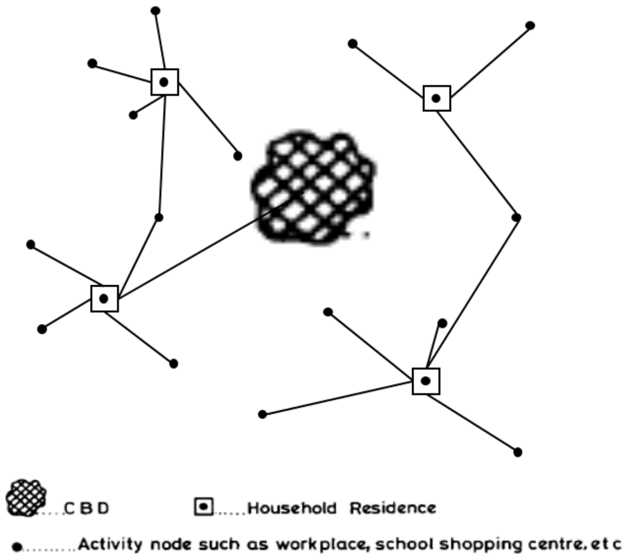


Figure 2. Activity pattern of a household in a hypothetical city, based on a nestling idea of residential choice [Modified according to Olatubara (1998: 65)].

Approach of elimination-by-aspect in residential choice

In reality, the information regarding each alternative might be incomplete and the decision-making process displays the bounded rationality mentioned in the previous section. Accordingly, Young (1984) proposes another approach to residential choice named elimination-by-aspect. This approach assumes that the decision-maker will apply the most important attribute first, and successively eliminate alternatives that fall below a certain level of acceptance (Young 1984).

2.2.3 The role of workplace location in residential choice

Commute to workplace is no longer the most important factor in residential choice

Concerning the relation between residence location and workplace location, Alonso’s (1964) urban theory model defines the workplace as an exogenous variable, which implicitly assumes that the causality runs from workplace location to residence location (Alonso 1964). Journey times to work and a person’s preference for commuting are significant factors in their residential choice (Ibeas et al. 2013; Handy and

Mokhtarian 2004). People generally locate in places with a maximal accessibility to jobs (Ibeas et al. 2013; Handy and Mokhtarian 2004). However, this assumption might not always hold true due to the following (Waddell 1993): Firstly, more and more short-term contracts or project-oriented employments are appearing in the flexible labor market nowadays. Housing arrival rates are not necessarily larger than job arrival rates. Secondly, when socio-economic and other spatial and environmental factors are also included, the accessibility to job location may become secondary in residential location choice (Sohn 2005: 316; Baccaini 1997; Kim, Horner and Marans 2005). Households do not make a residential location choice merely on the optimal commute situation. Instead, they accept various combinations of job-housing proximity within a range, as long as they are below a certain tolerance threshold (Van Ommeren, Rietveld and Nijkamp 1997: 417). An empirical study in Dallas-Fort Worth metropolitan area of the United States found that while 75% of households prefer to live close to their workplace, 25% of them prefer to live further away (Bhat and Guo 2004: 163). Many households are willing to endure the pressure of the commute if they find a residence that satisfies their preferences for other aspects (Einig and Pütz 2007: 78). In other words, the weight on job-housing proximity has been lifted and people will put more weight on other location factors (Hu 2014: 10). This is confirmed by the fact that those who have recently moved in general have a greater commute distance (Naess 2007: 152).

Causality might even run from residence to workplace

In fact, the causality between residence and workplace is often reversed. For instance, the empirical finding of Waddell et al. (2007) falls in line with that of Klammer and Tillmann (2002), in which it was demonstrated that 80% of surveyed households choose their residences first and later choose their workplaces based conditionally on the residence (Waddell et al. 2007). Households with more than one child, or with higher income, or with more than one car tend to choose residence before workplace (Waddell et al. 2007). In addition, a survey of high-technology firms regarding the important characteristics in location choice revealed that labor skills and availability are ranked as the most important determinants of location (Frenkel 2012). Knowledge-intensive financial service firms are also attracted by regions with access to highly competent and qualified workforces (Kronenberg 2013).

2.2.4 Residential choice varies among different population groups

Residential location choice is related to individual subjective perception of objective attributes

The previous sections elaborated the general key aspects in residential location choices. This section will continue to elaborate how individuals with distinct characteristics make their residential choices, since the final residential choice is the outcome of the trade-off between job accessibility, many other urban characteristics and individual characteristics (Kim, Horner and Marans 2005; Kim and Horner 2003). In other words, the decision to locate to a certain place is never determined by the objective measures of that place. Instead, it relies on the individual subjective perception or filtering of given objective attributes (Olatubara 1998: 63). Individuals with different characteristics will place various values on certain attributes of the residence, and in turn make distinct trade-offs in residential choices.

Socio-demographic attributes influence the residential choice

A households' life-cycle stage is defined by the age of the employed members as well as the presence and ages of children. Each of the life-cycle stages of households have various resource (time and budget) allocations (Beamish, Carucci Goss and Emmel 2001), which will result in different choices. For instance, family households usually pursue residences with direct access to the natural environment in a quiet neighborhood to maintain children's optimal health and development (Cummins and Jackson 2001). In contrast, single-person households tend to locate in a lively environment to maximize the accessibility to social networks (Storper and Manville 2006: 1253). In addition, income level, education level and mobility preference of an individual have an influence on the residential location. Young college-educated people prefer the amenity packages provided by urban areas as opposed to rural areas (Storper and Manville 2006: 1253). People with higher incomes will prefer larger housing at the cost of a longer commute (Waddell 1993: 77). Furthermore, an individual will intentionally choose locations that support their preference for certain travel modes. An individual who prefers cycling would live in residential neighborhoods with good bicycling-facilities (Pinjari, Bhat and Hensher 2009: 730).

Life-style influences the residential choice as well

Apart from the conventional socio-demographic attributes, lifestyle-associated preferences also play a significant role in the decision process (Holz-Rau, Scheiner and Sicks 2013; Kim, Horner and Marans 2005; Scheiner 2010). People with similar lifestyles tend to cluster together in a neighborhood, consume similar goods (housing included) and services (Beamish, Carucci Goss and Emmel 2001: 12). Beamish categorizes urban lifestyles into three groups: 'careerism' group, 'familyism' group, and 'consumership' group. Those in the 'careerism' group put a high value on the proximity to the workplace and try to minimize the time spent away from office. Those in the ‘familyism’ group put a high value on the space for family activities and spend a lot of time with family members. The ‘consumership’ group is driven by newest goods and services (Beamish, Carucci Goss and Emmel 2001; Bell 1968). Similarly, studies by BBSR (2015) find that urban-oriented small-size households without children have an outgoing lifestyle. Higher densities, functional mixture, adequacy of public spaces, and diverse supply of cultural and leisure opportunities weigh far more than the scarcity of open area in cities (BBSR 2015: 5). In contrast, non-urban-oriented households are more willing to raise their expenditure on the space of the dwelling and social homogeneity over the aforementioned factors, and at the same time are willing to accept the price of the long commute to their job (Musterd 2006: 1329).

2.3 Choice of workplace and its relation to residence location

Even though maximal accessibility to the job is not always the most important consideration in residential choices, the location of workplace is nevertheless one important spatial anchor. In addition, the choice of workplace is directly associated with the length of commute as well as the transport accessibility that conditions the choice of commute mode. Thus, this section will elaborate on the choice of workplace location and its relation to residence via commute. There are two approaches regarding job location choice. One approach considers the ‘restraint’ effect of the spatial separation between workplace and residence, and the other approach is based on the ‘lubricant’ effect of the commute.

2.3.1 Spatial proximity to residence location

Firstly, people usually seek jobs that are geographically close to their residence. In other words, the job search is sensitive to the geographical distance to the residence (Kim, Horner and Marans 2005). The job seeker usually starts from the place of residence to reduce both screening and searching costs as well as commuting costs. A job farther from the residence implies either increased commuting costs or additional costs for moving to a new residence that is closer to the job, which renders it less attractive (Kim, Horner and Marans 2005). This approach corresponds to the finding discussed above that the causality also runs from residence to workplace.

2.3.2 A better match between skills and job

Secondly, the location of workplace is dependent on the double requirement that the employee chooses the job and the employer simultaneously chooses the employee (Næss 2016: 15). This explains why people are in general more willing to travel further to work than they are for any other purposes such as schools, shops or social activities (Boussauw, Neutens and Wiltox 2012: 704; Hansen 1959: 74). In particular, specialized and skilled workers would expand the spatial range during their job search (Simpson 1987: 121; Watkins 2016). These workers would search for jobs over a wider area to maximize the return on their human capital investment (Simpson 1980). Whereas it is much easier for less specialized workers to find a job close to their residence (Naess 2007: 162), knowledge workers with specialized talents usually face a trade-off between a close geographical distance to the workplace and a satisfying job that matches their qualifications (Watkins 2016). Many empirical studies confirm that knowledge workers are more willing to tolerate a long commute for a better matching job, when the former could be compensated by the gains of the latter. For instance, Thierstein et al. (2006) find that highly specialized service workers in Zurich endure longer commuting distances than workers in other sectors, which is supported by the BFS (2016) (BFS Bundesamt für Statistik 2016: 3; Thierstein et al. 2006: 53). These results all confirm that mass commuting between suburban areas and large cities results from the structural mismatch between the jobs offered in new suburbs and the qualifications and specialization of residents there (Bontje 2007: 148).

2.4 The relevance of commute distance and time in locational choices

Commute is a spatially-related process underlying the labor market (Sang, O'Kelly and Kwan 2011: 906). It is the circulation space in the city, connecting production space (employment) and social space (housing) (Scott and Storper 2014: 8). Accordingly, the urban structure in terms of the distribution of housing and employment affects the length of commute trip. In addition, from a micro individual perspective, personal behavioral factors also play important roles in commute distance (Boussauw, Neutens and Wiltox 2012: 690). This section will introduce the commute distance and time firstly from a macro-spatial perspective and secondly from a micro-behavioral perspective.

2.4.1 Commute patterns in relation to urban structure, as well as the distribution and location of residences and workplaces

Aggregated urban structure (distribution of residences and workplaces) and commute pattern

Commuting distance is strongly influenced by the urban structure in terms of aggregated distribution of residences and workplaces. Naess (2007) comes up with three scenarios of urban structure in terms of residence and workplace distribution, and the associated commuting distance (Naess 2007). When workplaces are more centralized than residences, the inner-city residents usually have a short commute distance, whereas the employees in the inner city have a longer commute distance. When workplaces and residences are both concentrated in the inner part rather than the outer part of the metropolitan area, it contributes considerably to short commuting distance among inner-city residents as well as employees who work in the inner city. When the downtown area is an approximate point of gravity for workplaces and residences (simultaneously a node in the transport network), it contributes to some extent to shorter commuting distance among inner-city residents and employees whose workplaces are in the inner-city (Naess 2007: 155).

Location of residence and workplace and commute length

There is also research on the relation between specific workplace or residence location and the length of commute. The empirical study in Copenhagen, which has a monocentric spatial structure, suggests that commuting distance in general increases with the distance of the residence to the downtown area (Wang 2000; Naess 2007: 154). In contrast, there is no clear trend discernable in distance of workplace to downtown area and commute distance. The commute distance firstly increases and then decreases with the increase of the distance between workplace and the downtown area (Naess 2007: 154). The decreasing trend might relate to the phenomena that the less skilled workforce are frequently employed in places that are closer to their residence than downtown areas.

2.4.2 Theories on commute distance and time

An individual maintains a constant budget of commute time

Regarding the role of commute in the location choices from a behavioral perspective, there are two strands of argument. On the one hand, people's desire for residence and workplace proximity is underestimated and the ability of households to modify the situation of long commute is greater than researchers expected previously. Many households seem to search for low commuting costs, even if they do not limit themselves to the alternative with the least commuting cost (Korsu 2012: 1966). In most cases, residential or workplace changes will shorten the commute distance of at least one worker in two-worker households. Moreover, the theory of constant time budget assumes that a rational individual would periodically relocate their workplace and residence, or alter their commute behaviors in order to maintain a reasonable commuting time (Kung et al. 2014: 12; van Ommeren, Rietveld and Nijkamp 2000). This corresponds to the fact that urban commuting time has remained stable or increased only slightly in past three decades in spite of continuous population growth and increases in commuting distance and congestion (Gordon, Richardson and Jun 1991; Levinson and Kumar 1994; Crane and Chatman 2003; Kim 2008).

Individuals have a certain tolerance for commute

On the other hand, the commute time or distance is not that absolute. Instead, people are willing to tolerate long commutes for better residential and employment conditions. As long as the time is kept under the threshold level, there will be no direct motivations for further adjustments or changes. Collectively, empirical studies suggest that the tolerable commute time for one-way trip is in the range of 30min to 45min (Levinson and Wu 2005: 189). According to this theory, commute functions as a lubricant for labor market flexibility and residential adjustment, which permits the change of one of residence and workplace locations and keeps the other unaffected (Parr 2014). This explains why the commuting space expands with commuter trip lengths and the share of long commutes has increased year on year in European and North American metropolitan areas (Boussauw, Neutens and Wiltox 2012: 690; Banister 1997; Siedentop and Fina 2010; Guth et al. 2011).

Commute varies among different groups of population

The choice of commute is a trade-off between the benefits of better access to the job with the costs associated with the commute trip (Handy 2005). A greater commute tolerance is expected for a job better matching one's skills and offering better career prospects. Indeed, Burger, van der Knaap and Wall (2014) observed in the Randstad region that the commuting patterns of highly educated employees are regional wide, whereas less well-educated employees' commuting patterns are local scale oriented (Burger, van der Knaap and Wall 2014). Similarly, high-income individuals are more likely to be less sensitive to long commute distance compared to low-income workers due to the affordability of commute costs (Vovsha et al. 2012: 19; Naess 2007: 152), which is consistent with the finding of Li (2010) that commuting distance in general increases with income and occupational status (Li 2010). In addition, other socio-demographic situations also influence commute. Females typically have shorter commute time (Modarres 2011: 1199). The number of workers per household and the property status of the residence also have an influence on the commute distance (Boussauw, Neutens and Wiltox 2012: 690; Wang 2000). Last but not least, the employment conditions also generate effects on commute. Workers with the option of home-office and the availability of a company car tend to have longer commute distances (Frenkel, Bendit and Kaplan 2014, 2013b; Saxena and Mokhtarian 1997; Tayyaran and Khan 2003).

2.5 Choice of commute mode: impact of built environment versus. impact of mobility preference

Mobility behavior relates to both individual access resources and local access resources. Individual access resources include social status, physical status, professional status, income, possession of driving license and means of transport. Local access resources are related to the spatial characteristics, specifically to the presence of public transport stops, distance of residence from the nearest stop, and distance of the residence from the nearest stop of the alternative transport mode (Pellegrino 2012). In addition, individual attitude towards a certain travel mode also influences the mobility behavior apart from the aforementioned factors (Scheiner 2006; Handy 2002). Since the influence of individual access resources is not the main focus of this study, the focus will be on the relation between the commute mode and the spatial characteristics of the key spatial anchor (residence and workplace) as well as the mobility preference will be elaborated. Regarding the relative importance of these two aspects in determining the commute mode, there are in general two strands of research findings.

Built environment dominant mobility preference on the choice of commute transport mode

On the one hand, it is widely conceded that the spatial structure conditions people's choices of commute mode. For instance, Pellegrino (2012) finds that the share of car-usage per day increases with the distance between residence and city center (Pellegrino 2012). The location of workplace, either measured by the distance to the metropolitan core or the distance to the urban rail stations (Naess 2007: 162), is even more relevant in the commute mode choice. According to this viewpoint, new travel habits can be formed and travel modes will be changed when people relocate to a new place with a different built environment (Rodriguez and Rogers 2014: 537). The study conducted in Cologne reveals that only half of movers maintain their travel modes after their relocation (Scheiner 2006). Similarly, IMU (2002) report that after individuals moving to the outskirts of Munich from the city, the share of non-motorized modes decreased from 12% to 6% and the share of public transport reduced from 31% to 15% (IMU 2002: 112-113).

On the other hand, other researchers hold that residential location choice cannot satisfactorily explain for travel behavior, since both residential location choice and daily travel behavior belong to human actions guided by motivations (Scheiner 2005). Instead, it is the mobility preference, namely the attitude towards a certain travel mode rather than spatial structure that underpins the choice of a certain commute mode (Scheiner 2006; Handy 2002). This is termed residential self-selection, referring to ''the tendency of people to choose locations based on their travel abilities, needs and preferences'' (Scheiner 2006; Holz-Rau, Scheiner and Sicks 2013; Paleti, Bhat and Pendyala 2013; Litman 2005: 8; Mokhtarian and Cao 2008). Individuals with various travel-related attitudes will have different locational preferences, and this will guide them in choosing locations with access to corresponding travel modes, thus facilitating their travel behaviors (Bruns 2014). Empirical studies find that the residents' attitudes to certain kinds of neighborhoods (with different travel environments) largely explain the observed association between travel behavior and neighborhood characteristics (Paleti, Bhat and Pendyala 2013). This corresponds to the finding that living in cities is frequently associated with a car-free or car-independent lifestyle (Storper and Manville 2006: 1260).

Residential self-selection: individuals with certain mobility preference choose locations that facilitate usage of a certain travel mode

3 Knowledge typology, interaction pattern, and spatial implication

As mentioned in the comprehensive framework at the beginning of the second chapter, apart from the conventional characteristics of decision-makers, the new perspective of knowledge typology also influences spatially-related choices. The linkage between knowledge typology and knowledge workers' spatially-related choices is attributable to two aspects: one is the different importance of spatial proximity and different orientations towards the local external environment among each knowledge base; the other is the unique function of residence and commute among knowledge workers. This chapter focuses on the first aspect and the fourth chapter will elaborate on the second aspect. Firstly, the importance of social interaction and especially face-to-face interactions in knowledge creation and the significance of spatial proximity are demonstrated in the first section. Afterwards, the spatial logic of high-tech firms and APS firms with different focuses on tacit and codified knowledge are elaborated. Lastly, the analytical-synthetic symbolic knowledge typology is introduced. According to their sensitivity to geographical distance and their orientation towards the external environment, the different spatial logics of analytical, synthetic, symbolic knowledge firms are presented.

3.1 Knowledge creation, social interaction, and spatial proximity

This section firstly introduces the tacit component of knowledge and the importance of socialization in exchanging tacit knowledge. Then the importance of face-to-face interactions despite ICT development is demonstrated. Moreover, the relation between geographical proximity and knowledge creation is discussed and the importance of geographical proximity is established. Finally, various types of knowledge exchanges embedded in different geographical scales are illustrated.

3.1.1 Socialization, direct exchange of tacit knowledge, is essential in knowledge creation

Almost all knowledge has a tacit component

Only a segment of the knowledge embodied in individuals can be exactly expressed in codified language. This is termed codified or explicit knowledge. Codified knowledge can be articulated, processed, transmitted and stored relatively easily in the form of data, scientific formulae, specifications, manuals or blueprints (Nonaka, Toyama and Konno 2000: 282; Moodysson, Coenen and Asheim 2008: 1043). In contrast, the remaining non-communicable knowledge, such as subjective insights, intuitions and hunches, is termed tacit or implicit knowledge (Polanyi 1966: 4). Tacit knowledge is difficult to formalize, since it is deeply rooted in individuals' actions and experiences, as well as ideals, values and emotions (Nonaka and Nishiguchi 2000: 14). The meaning of tacit knowledge is highly culture and context-dependent (Polanyi 1966: 4; Storper and Venables 2004: 356; Malecki 2000). Tacit knowledge is essential in making use of codified knowledge to create new knowledge and value, and innovate (Schamp 2003: 181).

Four types of knowledge conversions in knowledge creation: externalization, combination, internalization, and socialization

Knowledge creation is a dynamic social process, "involving a dynamic interplay and exchange of implicit and explicit forms of knowledge among various actors"(Cooke et al. 2007: 46). Accordingly, there are four modes of knowledge conversion in knowledge creation: externalization, combination, internalization and socialization (Figure 3) (Nonaka and Nishiguchi 2000: 14-18). Externalization refers to the articulation of tacit knowledge into explicit knowledge forms such as metaphors, concepts, hypotheses, diagrams, models, or prototypes. As tacit knowledge is difficult to codify, Cooke et al. (2007) argues that the articulation of tacit knowledge even needs a third party with a background in the tacit knowledge or the community sharing the explicit knowledge (Cooke et al. 2007: 46). Combination refers to the integration of the explicit knowledge into more systematic explicit knowledge, which is a relatively spatially unbound process. Internalization refers to the conversion or embodying of the codified knowledge into tacit knowledge. It relies on one's comprehensive understanding of the explicit knowledge and the ability to link it with the existing system of knowledge. Internalization is in most cases realized via 'learning-by-doing'. Socialization is the exchange of tacit knowledge between individual actors within shared contexts. It is strongly facilitated by face-to-face interactions through joint activities and shared experiences (Nonaka and Nishiguchi 2000: 14-18).

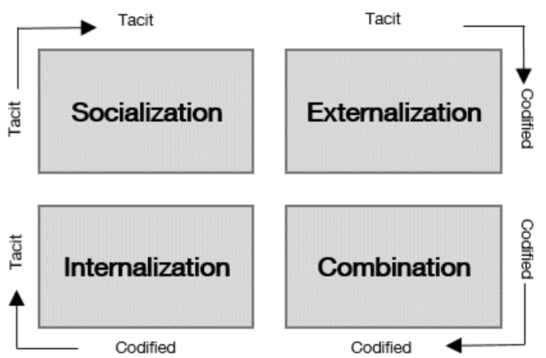


Figure 3. Four modes of knowledge conversion [Modified according to Nonaka and Nishiguchi (2000: 18)].

Social interactions are necessary for knowledge creation

Socialization is the most efficient way of exchanging tacit knowledge between different individuals, which is essential in knowledge creation. Without direct socialization, an individual who wants to exchange tacit knowledge with others will firstly depend on the externalization by other actors, and afterwards review and combine different kinds of codified knowledge. In the end, the individual has to link newly acquired systemic explicit knowledge with their existing body of knowledge and internalize them into tacit knowledge. Overall, this externalization-combination-internalization procedure is far more complex and less efficient than direct exchanges of tacit knowledge via socialization. The generation of innovation is a cumulative process in which economic actors benefit and learn through the collision of differentiated knowledge (Frenkel 2012: 252; Graf 2006; Jacobs 1969). In addition, the increasing complexity of research and development (R&D) activities, which can no longer be accomplished by individual innovators nowadays, requires interdisciplinary teams of researchers and entrepreneurs. Accordingly, there is an increasing demand for social interactions and networks as an important means for knowledge creation and diffusion (Boschma 2005: 69). Knowledge is interpreted also as a highly collective resource beyond individually embodiment, created through social interactions among individuals and organizations within certain social and cultural contexts (Lüthi 2011: 9).

3.1.2 Face-to-face interaction remains important in socialization, despite ICT development

Communication revolution appears exaggerated

Statements such as 'communications revolution', 'the death of geography' (Cairncross 1997) and 'the world is flat' (Friedman 2005) assume that geographical proximity and face-to-face contacts no longer play a key role in knowledge creation since the development of information and telecommunication technology (ICT) (Bentlage, Lüthi and Thierstein 2013: 47). These statements overlook the enduring and robust necessity of traditional human communication processes, namely cooperating and talking face-to-face.

Face-to-face interaction remains a fundamental human socialization

In fact, "despite the development of information and telecommunication technology, co-present face-to-face interaction remains the fundamental mode of human intercourse and socialization" (Boden and Molotch 1994: 278; Urry 2007). As Törnqvist (1968) argued, very important contacts still rely on direct face-to-face meetings between involved personnel (Törnqvist 1968: 101). For instance, initial idea-generation, strongly supported through face-to-face interactions among the associated actors, is significant for creating knowledge (Moodysson, Coenen and Asheim 2008: 1053). Florida (2002) also states that creative interactions can be established by the co-presence of creative agents in any given locality (Florida 2002a). The importance of face-to-face interaction is due to its advanced characteristics in the following respects. Firstly, face-to-face interaction is thick with information and guarantees the receiving of an exact message. It delivers more contexts than any other forms of human exchange, since it allows the body to 'talk' along aside the words and much information is present at a specific time (Boden and Molotch 1994). For complex context-dependent information, the medium itself contains the message (Storper and Venables 2004: 356). Through reading facial expressions, much positive or negative feedback can be received immediately. Secondly, face-to-face interaction is efficient. It allows immediate adaptation in the conversation and meeting time is thus used effectively to exchange the most important and relevant information. Since individuals have usually invested a huge amount of time, cost and effort in face-to-face interactions, actors give immediate attention to each other's remarks and interpenetrate in greater depth than any other forms of human exchange (Storper and Venables 2004). Thirdly, the commitments shown in face-to-face interactions will gradually increase mutual trust over time, thus facilitating future long-term co-operations in creating innovation-relevant knowledge (Cooke et al. 2007). Overall, face-to-face interactions strongly favor the exchange of innovation-related knowledge that requires a common language, understanding and trust (Storper and Venables 2004).

ICT development actually complements face-to-face interaction rather than substituting it

In addition, direct face-to-face interactions are even increasing, since virtual interactions enabled by ICT development complement them. Firstly, ICT primarily prepares the work that guarantees face-to-face communications at desired places, for instance, assembling materials, people and setting the appropriate place and so forth (Ibert 2010). Secondly, ICT also provides important tools in later stages to support and execute the agreements reached during face-to-face interactions (Urry 2007; Ibert 2010: 200). The connections facilitated by ICT ultimately rely on some form of intense social interaction and occasional face-to-face meetings, regardless of whether before or after (Engelbrekt 2011: 38). Overall, while ICT development might loosen some substitutable connections between actors and producers, most key connections are actually intensified (Urry 2007; Ibert 2010: 200).

3.1.3 The relevance of spatial proximity in knowledge creation

Spatial proximity per se is not sufficient for knowledge creation

Spatial proximity per se does not guarantee access to the local pool of knowledge, since other dimensions of proximity such as cognitive, organizational, social and institutional proximity between involved actors are also necessary for exchange of knowledge (Boschma 2005: 63). Active involvement in the network via face-to-face contacts to diffuse and create knowledge does not require permanent co-location and local embedding (Amin and Cohendet 2004: 105; Bentlage, Lüthi and Thierstein 2013; Breschi and Lissoni 2003), since they could also be realized through occasional travel (Boschma 2005: 69).

Nevertheless, spatial proximity does facilitate knowledge creation, when other proximities are constant.

Nevertheless, other factors being constant, a higher spatial proximity will strengthen the tie and facilitate both formal and informal exchanges of knowledge, which in turn effectively facilitates the creation of new knowledge and innovation. Firstly, the social, economic, and functional preconditions for collaborative learning are more likely to be achieved and sustained between co-located or neighboring actors (Ibert 2010: 188; Desrochers 2001; Nonaka and Nishiguchi 2000: 16). "Physical proximity is critical to break the ice" (Crescenzi, Nathan and Rodríguez-Pose 2013: 32). It facilitates accumulation of trust between actors involved, in turn to some extent substituting other dimensions such as social and cognitive proximity (Huber 2012: 1176). The co-location of actors in most cases offers a shared institutional context which constructs mutual trust and understanding (Malmberg and Maskell 2006), and increases relational proximity (Kirat and Lung 1999; Ibert 2010). Secondly, even when all these five dimensions of proximity are included, geographic proximity still generates a positive impact on tie formation (Balland, Boschma and Frenken 2015: 910). In many knowledge-intensive industries, users' suggestions and feedback are essential for innovation (Slaughter 1993), which is more easily realized by locating in proximate areas. As the former manager of DEC's workstation group in Silicon Valley pointed out that "physical proximity is important to just about everything we do" (Desrochers 2001: 37). When other proximities are constant, geographical proximity clearly facilitates and strengthens the ties in the knowledge network. That is why spatially-unbound networks are denser among actors that are proximate to each other (Boschma and Frenken 2007: 11), which will be elaborated in the following section.

Agglomeration economies concentrate geographically

Knowledge-intensive industries tend to concentrate geographically, since knowledge is easily shared and transaction costs for access gatekeepers, jobs and labor pools can be lowered via informal contacts and open communication channels in agglomerations (Kujath and Schmidt 2010), thus allowing networking and cross-fertilization (Currid and Connolly 2008; Cooke 2002; Cooke et al. 2007; Malmberg and Maskell 2002). Overall, interpersonal interactions or transactions are one of the mainstays of urban agglomerations (Storper and Venables 2004; Scott and Storper 2014). As Scott (2008) summarized, Metropolis represents a multidimensional force-field of social and economic proximities (Scott 2008). Firstly, the spatial concentrated diversity offers a setting where the space-time cost of multifaceted economic interactions are minimized. Secondly, the risks and uncertainties are shared among individual actors. These benefits are so powerful that many economic activities cluster together in specialized industrial districts in inner urban areas (Scott 2008: 789-790). There are two types of agglomeration economies: localization and urbanization economies (Sveikauskas 1975; Rosenthal and Strange 2001; Henderson 1986; Glaeser et al. 1992). Localization economies refers to the agglomeration of the same industry in one area, which corresponds to Marshall's externalities. "Something in the air" of Marshall (1927) actually refers to tacit knowledge, efficient trading of skills and jobs, and instantaneous access to dense agglomeration of labor pools and industries that occur by co-location in the same territory (Currid and Connolly 2008). Urbanization economies refers to the agglomeration of various related industries in one location, which corresponds to Jacob's externalities (Jacobs 1969). The structural link to the economic specialization in localization economies as well as cross-fertilization among various activities in urbanization economies are both important for innovation (Storper and Scott 2009: 163).

3.1.4 Various knowledge exchanges happen in different spatial scales

Local buzz and global pipelines complement each other

As mentioned previously, unintended interactions and learning even happen across a relational distance, given a shared space-time setting within the same local environment (Ibert 2010: 189). That is, informal spontaneous exchanges, communications and updates provide opportunities for learning and creating new knowledge between co-located actors (Trippl, Tödtling and Lengauer 2009; Bathelt and Karlsson 2008). The thick network that allows knowledge and inspiration to circulate between actors within a cluster is termed local buzz (Storper and Venables 2004). In addition, it is equally important to access the complementary external knowledge obtained via global knowledge networks (Cooke et al. 2007: 67). Global connections refuel and update knowledge creation, thus inspiring further developments. These types of knowledge exchanges across geographical distances are termed global pipelines (Cooke et al. 2007). Compared to the unintended transfer of knowledge in local buzz, global pipelines are targeted connections with certain sources of knowledge distributed remotely. Global pipelines and local learning complement each other and are both essential for knowledge creation (Bathelt, Malmberg and Maskell 2004). Knowledge-intensive firms need both the accessibility to networks to receive information and updated knowledge, as well as the critical mass to generate and benefit from knowledge spillovers (Bentlage, Lüthi and Thierstein 2013: 48).

Four types of knowledge exchanges: market relations, formal networks, knowledge spillovers, and informal networks

To describe more precisely the types of linkages to external sources of knowledge and partners, Trippl, Tödtling and Lengauer (2009) offers a comprehensive typology with two dimensions (static or dynamic knowledge transfer, formal or informal relations): market relations, formal networks, spillovers and informal networks (Table 1) (Trippl, Tödtling and Lengauer 2009). Market relations refer to the purchase of a product embodying existing technology and knowledge, which clearly extends beyond the region: either interregional or international links (Storper 1997; Sternberg 2000). Compared to market relations, formal networks involve long-term interactive relationships and further develop knowledge in a dynamic process in the long term. Associated partners share benefits, risks, opportunities and specific tasks. Since the match between specific technology and knowledge needs intensive search in extended spatial environments, formal networks are often beyond the local scale, and those in knowledge-based industries are among international partners. Apart from these two formal/traded relations, knowledge spillovers and informal networks as informal/non-traded relations are also important types of knowledge exchange (Trippl, Tödtling and Lengauer 2009: 449).. Knowledge spillovers refer to externalities of knowledge acquired during interactions without compensation for the transfer. They are often limited to the local scale, for instance through informal face-to-face interactions, mobile labor force (Almeida and Kogut 1999), or simply monitoring other competitors in the market. Knowledge spillovers decay with distance. Informal networks between companies and organizations will cooperate with each other in understanding problems and discussing possible strategies. The collective learning between actors via informal networks enhances the local knowledge base and innovation ability in the long term. As informal networks are trust-based, they are tied to a specific locality or region to facilitate personal relations and face-to-face interactions, as well as a shared understanding (Trippl, Tödtling and Lengauer 2009: 449). To summarize, informal relations that exchange tacit knowledge are more locally- or regionally-oriented, whereas formal relations are beyond local or regional scale.

Table 1. Types of knowledge exchange (linkages to external sources of knowledge and partners) in innovation process [Modified according to Trippl, Tödtling and Lengauer (2009: 448) and Cooke et al. (2007: 64)].

	Static (Knowledge transfer)	Dynamic (Collective learning)
Formal/Traded relation	*Market relations* e.g. Contract research, consulting, licensing, buying intermediate goods.	*Cooperation/ Formal networks* e.g. R&D collaborations, shared use of R&D facilities.
Informal/Untraded relation	*Knowledge externalizations and Spillovers* e.g. Recruiting specialists, monitoring competitors, participating fairs and conferences, reading scientific literature, patent specifications.	*Milieu/Informal networks* e.g. Informal contacts

3.2 Different spatial logics among high-tech and APS firms in knowledge economies

High-tech industries and advanced-producer-services are two main pillars of knowledge economies (Lüthi, Thierstein and Goebel 2010: 115; Thierstein et al. 2006: 35). Due to the different importance of tacit and codified knowledge in these two economic sectors, knowledge-intensive firms in high-tech industries and APS sectors are associated with distinct types of interactions and in turn different spatial logics. This section will start by examining their different demands for spatial proximity and local connections. It then goes on to introduce other factors such as spatial scale of the market and the production space that influence spatial logic.

3.2.1 Different importance of spatial proximity and local connections

Different requirements of spatial proximity in knowledge exchange

Zillmer (2010) classifies knowledge-intensive industries into high-tech industries, transformation-oriented services, transaction-oriented services, and information and media services (Zillmer 2010: 114-122). High-tech industries produce knowledge-intensive material goods by integrating new knowledge in products and processes (Kujath and Schmidt 2010: 45). After the invention of new products, transformation-oriented services generate non-material inputs into material-focused parts of the industry to shape and refine the product (Zillmer 2010). Transaction-oriented services organize and manage economic transactions (Kujath and Schmidt 2010: 46). Advanced-producer-services such as insurance, financing and legal services belong to transaction services. Information and median services transform knowledge into digitalized knowledge or information products. Cultural industries and processing of data and information belong to media and information services. Empirical studies of the maritime economies reveal that spatial proximity is more important for transaction-oriented processes, which are based mainly on tacit knowledge, compared to transformation-oriented process, which are based mainly on codified knowledge (Bentlage et al. 2014: 280). Münter and Volgmann (2014) report that transaction-oriented services and information and media sectors in the Rhine-Ruhr metropolitan region prefer central locations in large agglomerations to facilitate the interaction with smaller transaction costs. In contrast, high-tech industries and transformation services tend to concentrate on the peripheries of city-regions, since they are specialization-oriented to sharing basic facilities rather than accessibility (Münter and Volgmann 2014: 13).

Different intensities of local vs. nonlocal connections in knowledge creation

Furthermore, different types of networks among high-tech and APS firms influence their locations. Being located close to customers and suppliers is far more important than being proximate to the exploration of knowledge, since it allows APS firms to have better anticipatory knowledge concerning contracts, which directly influences or even determines success and development (Cooke et al. 2007: 87). Hence, knowledge-intensive service firms concentrate and remain in densely population regions (Kronenberg 2013). In contrast, the frequent use of codified knowledge among high-tech industries will be less bound to the local scale. Indeed, the share of global linkages among all intra- and inter-firm relations among high-tech firms has been found to be larger than that of APS firms within the metropolitan region of Munich (Lüthi, Thierstein and Goebel 2010; Lüthi, Thierstein and Bentlage 2011, 2013). Linkages with international locations generally rank high among high-tech industries, whereas most national locations appear in the ranking of APS-linkages (Goebel, Thierstein and Lüthi 2007). This corresponds to the observation that more high-tech firms locate on roads with better regional closeness, whereas many APS firms locate on roads with better local closeness (Alaily-Mattar et al. 2013). Closeness measures the mean distance of the shortest path to all the other vertices/nodes in the network. Local closeness refers to the mean distance to other links within 1km. Regional closeness refers to the mean distance to all the other links in the region (without a distance threshold). Similarly, high-tech industries are usually located in low density suburban areas (Spencer 2015), especially with good access to highways and more parking spaces (Maggioni 2002). Furthermore, high-tech firms containing many interactions tend to simplify the communications to the local environment, whereas APS firms engaging in many inter-firm connections will orient themselves towards more communications with local environment (Spencer 2015), which will be elaborated in detail in section 3.3.3.

3.2.2 Different spatial scale of market and production space

High-tech firms associate with strong global relationships, which are not restricted to national markets to offer daily supplies in the way APS firms often are. For instance, whereas the automotive industry is 'footloose' (Bentlage, Lüthi and Thierstein 2013: 56; Sturgeon, van Biesebroeck and Gereffi 2008: 318), advanced business services "continue to be extremely strongly concentrated geographically" (Dicken 2011: 390). This explains why local congestion negatively influences the location of firms focusing on higher-ordered office activities, compared to positive influence on firms focused on production-related activities (Hou 2016).

In addition, different requirements of space among high-tech and APS firms also result in their different spatial logics. Locational convergence or clustering are expected when the production process are labor-intensive and vertically disintegrated. APS firms are able to afford higher land rent in inner urban areas owing to the fact that they require relatively less space as well as their higher productivity per unit of land. In contrast, large capital and land-intensive high-tech plants will disperse outwards towards the periphery of the land use system (Scott 1983), which is consistent with the finding by Frenkel (2012) that high-tech firms in established stages in most cases locate themselves in the outlying part of the metropolitan region (Frenkel 2012). Similarly, Duranton and Puga (2005) find that production sites seem to be located in peripheral regions, whereas management functions remain and concentrate in cities (Duranton and Puga 2005).

3.3 Analytical-Synthetic-Symbolic knowledge typology, knowledge creation mode, and spatial implications

It is worth emphasizing at this point that the plurality of knowledge is more complex than the binary tacit-codified division implies. Creation of different types of knowledge involves different social interactions with various dependencies on the spatial proximity, resulting in unevenly distributed knowledge flows and distinct spatial patterns (Spencer 2015). This section firstly introduces the analytical-synthetic-symbolic knowledge typology. Following this, the different sensitivities to the geographical distance of each knowledge base are elaborated. Subsequently, different modes of knowledge production and interaction contexts in relation to an organization and their impact on orientation towards the local external environment will be introduced. Lastly, this section will outline the spatial implications, namely the spatial logics of analytical, synthetic and symbolic knowledge-intensive firms.

3.3.1 Knowledge typology is more complex than the tacit-codified division

Knowledge typology is more complex than simply dividing into tacit and codified knowledge. The binary tacit-codified division has been criticized for its narrow understanding of knowledge, learning and innovation (Johnson, Lorenz and Lundvall 2002; Asheim, Boschma and Cooke 2011: 896). Many researchers have attempted to go beyond this simple dichotomy. Blumentritt and Johnston (1999) propose a classification that ranges from easily transferable codified knowledge, via common knowledge (accepted as standard without having been made explicit) and social knowledge (concerning interpersonal relationships and cultural issues), to embodied knowledge (personal experience and skills) (Blumentritt and Johnston 1999). Another distinction suggested by Jensen et al. (2007) is between know-what (knowledge about facts), know-why (knowledge about principles), know-how (skills) and know-who (knowledge about other "knowers") (Jensen et al. 2007). Asheim et al. (2007) introduce a comprehensive knowledge typology (analytical-synthetic-symbolic knowledge base) (Asheim et al. 2007: 143-146). This study is based mainly on this knowledge typology, since it "takes into account of the rationale of knowledge creation, the way knowledge is developed and used, as well as the interactions between actors in creating, transmitting and absorbing knowledge" (Asheim, Boschma and Cooke 2011: 897).

3.3.2 Analytical-Synthetic-Symbolic knowledge typology has various sensitivities to geographical distance

The features of analytical knowledge

This part will introduce the main characteristics of each knowledge base including the knowledge creation process, its tacit component and context dependency, related activities and industries, as well as the innovation pattern (Table 2). Analytical knowledge, also known as 'know-why' knowledge, concerns principles and causalities. Analytical knowledge creation is closely associated with science-based industries and tries to understand and explain features of the natural system. It requires a firmly rational, formalized deductive approach and follows certain procedures. Since analytical knowledge has a strong codified content, namely in most cases being condensed and codified in scientific publications, is relatively context independent (Moodysson, Coenen and Asheim 2008: 1046). Associated research collaborations exist between and within research institutes, or between firms and research organizations (Asheim et al. 2007: 144). The outcomes of innovation are radically new inventions or products. Analytical knowledge creation spans a large spatial range; it could involve nearby as well as distant partners, forming both global and local networks.

The features of synthetic knowledge

Synthetic knowledge, also known as 'know-how' knowledge, concerns skills or procedures. Synthetic knowledge creation refers to design artifacts or objects (embodying new synthetic knowledge) with certain functions to solve a practical problem (Asheim, Boschma and Cooke 2011). The innovation is incremental and dominated by modifications to existing products and processes. Synthetic knowledge can only be partially codified. The creation of synthetic knowledge is relatively context specific, whereby a common social and institutional context is a prerequisite setting for interactive learning processes. Considering that short feedback loops are important to speeding up the design of product and services, the frequent forms of interactions associated with synthetic knowledge creation are dense communications with customers and suppliers (Moodysson, Coenen and Asheim 2008). Accordingly, local collaborations are preferable in this case (Asheim et al. 2007: 144-145).

The features of symbolic knowledge

Symbolic knowledge, also known as 'know-who' knowledge, is knowledge about other potential collaborators with complementary specializations (Christopherson 2002). Symbolic knowledge creation concerns creating cultural meanings based on one's specific experiences and novel interpretations within a loose, usually localized network of other involved actors (Moodysson, Coenen and Asheim 2008), and is closely associated with creative, cultural industries such as media, fashion and advertising. Symbolic knowledge is strongly context specific and most sensitive to geographical distance, which is to say it is highly variable between places, classes and genders, since it deals with cultural knowledge and sign values (Asheim and Hansen 2009: 430). Hence, the acquisition and creation of symbolic knowledge is only accomplished through learning-by-doing in studios or project teams, which is strongly facilitated by co-locations or spatial proximity (Asheim et al. 2007: 145).

Different requirements of spatial proximity among each type of knowledge base

To summarize, the more codified the knowledge is, the smaller the sensitivity of knowledge creation to geographical separation tends to be (Moodysson, Coenen and Asheim 2008). External analytical knowledge could be accessed via reading and understanding published documents, thus the creation of analytical knowledge is not limited to close-by partners, but could be realized among actors distant from each other. In contrast, synthetic and symbolic knowledge are more dependent on interactions with local people and knowing their actual needs and desires. The creation of synthetic knowledge is to some extent limited to the collaboration on the local scale (Moodysson, Coenen and Asheim 2008: 1053). Symbolic knowledge creation is highly dependent on frequent negotiations with the evaluators or users within a shared context, which is strongly concentrated on the local scale. To summarize, symbolic knowledge and analytical knowledge are extreme types on a spectrum in terms of preference for spatial proximity, while synthetic knowledge lies between them (Pina and Tether 2016: 411).

Table 2. Characteristics of analytical-synthetic-symbolic knowledge base [Modified according to Asheim et al. (2007: 146); Asheim, Boschma and Cooke (2011: 898); (Asheim and Hansen 2009: 430); Spencer (2015: 885-886); Moodysson, Coenen and Asheim (2008: 1047)].

Key features	Knowledge typology		
	Analytical knowledge (*know-why*)	Synthetic knowledge (*know-how*)	Symbolic knowledge (*know-how, know-who*)
Knowledge creation process	Developing new knowledge about natural systems by applying scientific laws; Deductive way	Applying or combining existing knowledge in new ways in order to design or construct something with functional goals (Simon, 1969) Inductive way	Creating meaning, desire, aesthetic qualities, affect, intangibles, symbols, images based on human experience and their understandings. Inductive way
Interaction actors	Collaboration within and between research units, between firms (R&D department) and research organizations	Interactive learning with customers and suppliers	Learning by doing, in studio, project teams and many other diverse interaction types
Tacit Component	Strong codified knowledge content,	Partially codified knowledge,	Strong tacit component,
Relation to context	Context independent, highly abstract, universal meaning relatively constant between places	More context specific meaning varies substantially between places	Strong context specificity Meaning highly variable between places, classes and genders
Related industries	Science-intensive industries	Industries with a technological focus.	Cultural and creative industries involving a high level of aesthetic value.
Outcome of knowledge creation	The knowledge itself	Tangible and concrete artifacts with use value	Meanings, symbols, images as well as intangibles
Innovation pattern/ Relationship to established economic structure	Radically new inventions or products. Less sensitive to the existing economic structure	Incremental and path-dependent innovation, mainly modify existing products and processes. Closely linked to institutions and organizations that constitute the regional economic structure	Innovation depends on both the creator and evaluator. Less sensitive to the existing economic structure and more attracted by diversity

3.3.3 Mode of knowledge creation and organizational context influence the orientation towards local external environment

Algorithmic vs. heuristic knowledge creation; convergent vs. divergent thinking.

The creation of symbolic knowledge based mainly on the subjective values of both the creator and the evaluators. The creation of symbolic knowledge is rather heuristic. Consequently there is no single prescribed way of achieving it and therefore divergent thinking is frequently applied in the process (Spencer 2015: 886). Accordingly, symbolic knowledge associated with heuristic knowledge production and divergent thinking requires a large network with many strong- and weak-ties/connections, allowing them maximal exposure to influences. In contrast, the knowledge creation in science and technology industries is rather algorithmic, and is observable and repeatable by others (Spencer 2015: 885). This process is associated more with convergent thinking, implying that there is a single optimal way to attain the functional goal by combining existing knowledge. Hence, analytical knowledge associated with algorithmic knowledge production and convergent thinking usually involves a smaller and more focused network.

Intra-organizational vs. inter-organizational context associates with the orientation towards external environment

Furthermore, the 'context' proposed by Storper (2009), refers to a collective environment in which actors coordinate with one another to reduce uncertainty (Storper 2009: 13). Different anchors and frameworks for individual actions are formulated and stabilized in a certain environment (Storper and Salais 1997). "The more organizationally internalized the actor's relationships, combined with the effects of the internal division of labor in an organization, the more an actor's context is intra-organizational and possibly task specialized. In turn, this will direct the actor's communication within the organized chain and tend to simplify communications to the local, external environment. At the other extreme, shallow or artisanal divisions of labor and less "purified" definitions of tasks will depend on more diverse, irregular, and uncertain external communications" (Storper 2009: 13). For instance, using the network language, creative workers require more weak-ties than science- and technology-based workers (Spencer 2015: 886). Amabile (1996) also offers support from a psychological perspective that cue-rich environments might provide a level of cognitive stimulation for individuals to engage in their creativity relevant skills (Amabile 1996: 228). The notion of context could be extended into behavioral economics, meaning that different types of communications with the local external environment require certain corresponding geographical locations. Frequent engagements in external communications are associated with more diverse and urban local economies, as opposed to specialized and less urban locations (Duranton and Puga 2000).

3.3.4 Spatial logics of knowledge-intensive firms based mainly on analytical, synthetic, and symbolic knowledge

Bathelt and Glückler (2011) state that Interactive learning has "distinct consequences for the spatial organization of production and innovation" (Bathelt and Glückler 2011: 43). Following the detailed understanding of knowledge creation process corresponding to each knowledge base and its association with spatial proximity, the spatial logics of firms based on the main knowledge base will be explained in this section.

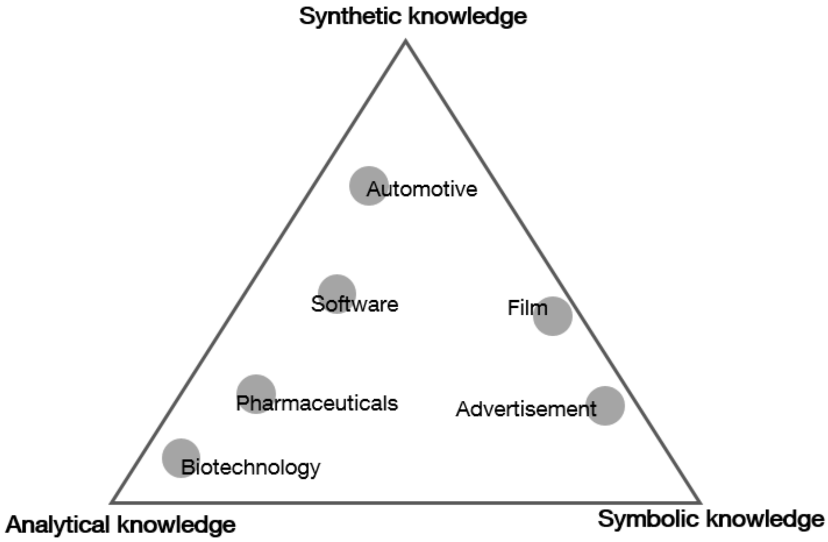


Figure 4. Primary knowledge base applied in certain knowledge-intensive industries. [Modified according to Asheim et al. (2007: 146)].

Categorization of analytical-synthetic-symbolic knowledge firms based on their primary knowledge base

The threefold analytical-synthetic-symbolic knowledge typology refers to ideal-types. Firms in most cases combine knowledge bases to varying degrees, "roughly in a continuum from (pure) analytical knowledge to (pure) symbolic knowledge" (Strambach 2008; Pina and Tether 2016: 411). To identify which particular knowledge base dominates is contingent on the characteristic of the innovative activities in the industry. Figure 4 provides examples of firms according to their main knowledge base. For instance, biotechnology firms mainly use analytical knowledge. Advertising firms mainly apply symbolic knowledge, and automotive industries predominantly use synthetic knowledge (Asheim et al. 2007: 146).

Spatial logic of firms based on analytical knowledge

For science and research activities based mainly on analytical knowledge, it is easier to transmit knowledge using easy-to-transmit codes and numbers that can be understood by researchers and co-workers. Much analytically produced scientific knowledge is condensed and codified in scientific publications. Hence, the knowledge exchanges within science-based industries are less dependent on frequent face-to-face contacts through local networks. Nevertheless, to maintain good access to global research communities, science-based industries also show a tendency to concentrate in the nodes of networks such as large metropolitan regions (Asheim and Hansen 2009: 432).

Spatial logic of firms based on synthetic knowledge

Synthetic knowledge creation benefits strongly from the proximity between associated producers and users. Local customers play an essential role in conceptualizing and developing a new product, since these activities involve many hands-on, trial-and-error experiments with concrete prototypes of the envisaged product, or negotiation of the specific services. Short feedback loops can speed up these processes and contribute to create most innovations to a large extent (Desrochers 2001: 37-38). Accordingly, the more specialized and advanced a service activity, the more likely it concentrates in large cities. In contrast, standardized services tend to be migrated to customers of inputs (Coe and Townsend 1998; Desrochers 2001: 32).

Spatial logic of firms based on symbolic knowledge

For cultural and symbolic industries, three spatially-bound social processes are essential: cross-fertilization across different creative industries, decreased transaction costs, and informal networking to attain new jobs and projects (Currid and Connolly 2008: 429). Urban areas with physical proximity, density, openness, diversity and interaction strongly facilitate these three social processes (Spencer 2015; Brake 2015). Firstly, highly aesthetic, symbolic, and experiential products are taste-driven and quite subjective, meaning that the value depends how much people like them (Power 2009; Asheim and Hansen 2009: 432). Creative ideas often originate through spontaneous exchanges about 'shared life experiences' within a specific social-cultural-spatial context, rather than a study of the market. Secondly, cities provide stimulation and opportunities to take up the synergy effect. 'Attraktive Örtlichkeiten (Attractive localities)' provide a special milieu and synergy effect. The city itself functions as a lively arena equipped with many diverse and urban sites and spaces for interactions in restaurants, cafes, bars, as well as performance venues. People's tastes are easily negotiated, understood and eventually constructed via intensive social engagements and face-to-face contacts facilitated by these urban public spaces (Currid and Connolly 2008: 427). Thirdly, the borders between production and consumption of cultural products are blurred within a city (Spencer 2015: 887). Many cultural workers gain opportunities simply by running into other cultural workers such as editors on the street of cities. One fashion designer reported that "informal networks are probably the most powerful driver, pretty much everyone we work with we have a personal relationship with" (Currid 2007: 81). Hence, activities using symbolic knowledge have a high city affinity and cluster the most, which functions as the glue of established urban centers (Currid and Connolly 2008: 427).

Firms with different type of networks have different locations

To summarize, networks of academics exist in national or international scale. In fashion, public relations and the arts, in spite of elite international networks at the highest level, networks usually are highly localized. For financial services and high technology industries, local networks and long-distance networks coexist and intersect with each other (Storper and Venables 2004: 356). Accordingly, various empirical findings regarding their locations are consistent with the spatial logic of the each type of knowledge-intensive firm. Firms using a primarily symbolic knowledge base are more likely to locate in hub or capital cities, whereas firms primarily having an analytical knowledge base are relatively more likely to be located in cities outside of the main metropolitan areas (Pina and Tether 2016: 407-408). Firms with a synthetic knowledge base are more likely to be located in smaller towns and rural areas. Additionally, Musterd (2006) finds that cultural and creative industries in Amsterdam are distributed more in the older, smaller and mixed urban structures Musterd (2006: 1328), whereas industries such as high-tech hardware, software production, financial and marketing support tend to be located in more peripheral parts of the city (Hall and Castells 1994).

4 Knowledge-intensive jobs and spatially-related preferences of knowledge workers

The previous chapter introduced the characteristics of knowledge typology with different sensitivities to spatial separation and orientations towards local environment, without specifically addressing the connection to individual spatially-related choices of residence, workplace and commute. Hence, this chapter attempts to bridge previous chapters by examining how different rationales of knowledge creation in jobs penetrate the sphere of residence and commute among knowledge workers. Firstly, how built environment influences the opportunities for encounters between individual agents is elaborated. Secondly, the distinct perception of residence, workplace and commute by knowledge workers will be presented. The final section will present three interrelated research hypotheses based on the overall conceptual background.

4.1 Built environment influences types of interactions

Despite the development of information communication technology (ICT), most human activities are still conducted in real physical spaces or certain locations. The city is not only a focal point for interactions to happen, but also characterized by continual iterative processes between people and people, as well as people and the environments they inhabit (Spencer 2015: 887; Scott 2010: 121). Firstly, the spatial arrangements (relative location) of residential locations, workplace locations, as well as public spaces including restaurants, cafés, parks and streets will influence the possibility of informal interactions and the subsequent exchanges and learning processes after those intentional contacts are executed during the workday (Spencer 2015: 894-895). Furthermore, the specific design of buildings, especially the space between buildings, also influences the types of relations among individuals that live or work within them. Neighborhoods with high proximity enable a larger probability of direct face-to-face interactions and unplanned encounters for interactive learnings (Spencer 2015: 894-895). In some cases, simply by watching the successes and experiences of others, even without direct interactions, people in these areas can learn from each other (Desrochers 2001: 43). Owing to these rich opportunities for interaction, the old city center provides not only urban living, but facilitates entrepreneurship (Storper and Manville 2006: 1259).

4.2 Knowledge workers' distinct perception of residence, workplace, and commute

Knowledge workers with a higher position in the organization have great responsibilities and generally make complex and far-reaching decisions, thus engaging more frequently in socializing and networking (Scott 2008: 802). They seek opportunities for self-actualization in work as well as in daily activities and even leisure life (Jemielniak 2012: 115; Thrift 2005). Thus, job, residence, and even the commute, as key anchors of individual activity space influencing the opportunities of interaction will be loaded with meanings beyond simply a job, a dwelling, or a commute trip.

4.2.1 The workplace is more than earning a living

Agglomerations attract talented individuals to work there

Dense areas act as 'random generators' of contacts, information and opportunities (Läpple 2004), thus risks are shared, and exchanges are enforced (Duranton and Puga 2005, 2001). Talented and ambitious individuals are more productive, more likely to learn from each other, and more innovative at higher densities (Jacobs 1969; Lucas 1988; Marshall 1890; Moretti 2004; Cooke 2014; Glaeser 1999). Analogous to the network effect introduced by Rohlfs (1974) that each additional talented worker implies a large gain of further potential exchanges and opportunities for co-operations among workers within the whole network (Rohlfs 1974), the agglomeration effect of large cities will exponentially increase with the number of highly qualified workers. Accordingly, agglomerations function as 'sticky places' and attract more and more human capital as a place to work (Markusen 1996).

Relative location to the whole industry is important in choice of workplace

A job is not regarded merely as a means of earning a living. Knowledge workers also regard their job as a way of exploiting and creating new knowledge, as an opportunity for facilitating their career and achieving self-actualization. To maximize the value of knowledge creation, knowledge workers tend to be continuously seeking jobs that match better with their expertise and skills. In other words, knowledge workers do not see themselves as limited to their current job, but also take the concentration of the related industries into account during their job search (Florida 2015).

Local meeting places near the workplace location are also relevant

In addition, knowledge workers are the basic units that realize the interactions between firms that in some cases also happen beyond the firms. Hence, the availability of local meeting places, such as restaurants, cafes, bars that support informal or subsequent after-work meetings are also an important consideration in job location choice (Saxena and Mokhtarian 1997: 127; Spencer 2015: 894).

4.2.2 Residence is more than a dwelling for knowledge workers

Residence is a place of self-expression, instead of a mere dwelling

Place of a residence implies more than geographical location for knowledge workers. Firstly, "selecting housing is a process of knowing who we are and how our houses can express ourselves" (Beamish, Carucci Goss and Emmel 2001: 21). Knowledge workers with higher social-professional status select the residence that best matches their whole way of living and working. For instance, Florida (2002b) found that the clustering and concentration of creative workers is closely associated with a tolerant and bohemian atmosphere (Florida 2002b). In contrast, the residential neighborhoods of conservative synthetic high-tech workers are in most cases characterized by quietness, and adequate natural amenities such as green spaces (Spencer 2015).

Home location influences individual action and activity space

Furthermore, residential location influences individual action space and activity space (Horton and Reynolds 1971: 41). Action space is an important term in understanding the interaction between spatial structure of cities and spatially-related behaviors of residents in cities (Horton and Reynolds 1971: 47). The action space of an individual refers to the overall collection of all urban locations about which the individual has information and the associated subjective utility or preference for these locations based on actual and potential spatial behaviors (Horton and Reynolds 1971: 37). Activity space refers to the subset of all urban locations that the individual has direct contact with during actually conducting their daily activities (Horton and Reynolds 1971: 37). Apart from the impact of the objective spatial structure, home location and the length of time the individual lives in the residence are closely associated with one's action space, and in turn activity space. Overall, residential location is a key spatial anchor in individual action space and also influences the actual details of daily activity patterns (Waddell 2001: 14).

Home office: residence as a production space

In addition, home office working is enabled with the advancement of ICT development, since some knowledge creation can be realized independently from the fixed physical workplace. This new function (space of production) attached to the residence results in a different requirement in terms of locational attributes when knowledge workers select their residential location. They might choose locations with good access to airports and business service centers (Ellen and Hempstead 2002: 752).

Residence influences social contacts and interactions

In short, residence is a setting, milieu, circumstance and condition individuals' "social pattern of contacts" (Næss 2006: 25), above and beyond its function as a dwelling or a shelter(Beamish, Carucci Goss and Emmel 2001). Social interactions embedded in the course and pattern of daily activities refer to the total number and types of contacts as well as the corresponding spatial proximity. The frequent activities that knowledge workers in the Munich region engage in include going out to cafés or bars, eating out, visiting friends, or walking around the city center (Hafner, Heinritz, et al. 2008). For instance, the sectoral form of out-migration outwards along the center-outer axis of suburbanization reflects people's attempt to maintain daily relationships after migration (IMU 2002: 35-36). Knowledge workers select residential locations that support their social pattern of contacts and provide the inspirations that their job requires (Helbrecht 1998; Schirmer, van Eggermond and Axhausen 2014; Næss 2006: 25). Given that spontaneous and informal contacts are essential to initiating business, artists must reside in the specific place that guarantees close proximity to important cultural gatekeepers, since a regional network is not adequate for artists hoping to create the necessary social scenes (Currid and Connolly 2008: 427).

4.2.3 Commute is more than a trip for knowledge workers

Commute route is the key axis of activity space

The type of interaction corresponding to each type of knowledge base correlates with different patterns of action space, and in turn influences the preference for a certain travel mode during a commute trip (Golledge 1997; Saxena and Mokhtarian 1997). Each person's knowledge about the city he or she resides in is geographically specific. In most cases, the individual has a good knowledge about the route from one's home to major destinations, for instance the job location (Adams 1969). In other words, the route between the workplace and the residence constitutes important segment of individual activity space, functioning as reference anchors for conducting other activities (Saxena and Mokhtarian 1997: 128; Hägerstraand 1970). Knowledge workers will also consider the relation between their commute route and their current as well as potential activities in the choice of commute mode.

Commute time could be effectively used for knowledge creation

In addition, the role of commute differs also from their mode of knowledge creation, since the commute trip might involve diversions and activities that go beyond the mere aim of reaching the workplace. Some knowledge workers (analytical high-tech workers and symbolic APS-workers) can indulge in footloose working practices during the commute trip, since analytical and symbolic knowledge creation are not necessarily bound to fixed physical workplace. The commute time could be effectively exploited for multiple ends. Hence, the environment surrounding the commute path is also be taken into consideration when analytical high-tech workers and symbolic APS-workers are choosing the mode of transport to commute. Florida (2002b) stresses the importance for creative workers of using active modes to feel the surrounding world, “as the world is unfolding around you” (Florida 2002b: 180).

The experiential dimension of mobility along the commute cannot be ignored

Moreover, different modes of transport create a different atmosphere or ‘chemistry’ that the individual commuter experiences. Apart from the maintenance effect of mobility, the experiential dimensions of mobility are also crucial (Van Kempen and Wissink 2014; Hutchinson 2000; Kennedy 2004; Bissell 2013). That is, the commute is not simply about reaching one’s destination, but also corresponds to “the expectation of newness, the desire for knowledge as well as the search for the meaning of everything and of the existence itself”(Colonna, Berloco and Circella 2012: 90-91). For instance, one of the most salient characteristics of public transport is the sheer density of people transported together in close proximity. To be a passenger in public transport is to be exposed to other unknown near-dwellers and being with other people as a series of relational practices (Bissell 2010: 270). Specifically, the mobile individual is actually prone or exposed to various other individuals or things during the journey (Bissell 2013: 357). The behaviors of the proximate passengers, together with the silence or muted conversation in the bus or train, creates a certain atmosphere, namely “something sensed often through movement and experienced in a tactile kind of way” (Bissell 2010; Urry 2007: 73). Accordingly, it unconsciously drives people’s intention to act in a certain way. For instance, observable busyness of other passengers might encourage individuals to feel more primed to continue working rather than engaging in other practices (Bissell 2010: 274). Overall, traveling with different modes equates with different exposures to interactions: travelling with public transport and active modes intentionally and unintentionally involves in more direct and/or indirect interactions with the surrounding people and environment, whereas driving or sitting in a car is comparatively less engaged in the external environment.

4.3 Research hypotheses: Knowledge workers optimize the use of space corresponding to their networks of interaction

As the basic units of knowledge creation in knowledge economies, knowledge workers make choices that ‘express and nurture’ their ability to create knowledge to sustain their competitiveness analogously to knowledge-intensive firms. Different sensitivities of the knowledge base to geographical distance, together with various associated contexts and knowledge production modes, will result in the formation of different types of networks and even different tolerances of commute among each group of knowledge workers. There are no pure spatial behaviors, but rather social needs localized and manifested in a certain space (Bathelt and Glückler 2011: 24-27). Specifically, knowledge workers would optimize the choices of specific space that they immerse in or inhabit to match with their rhythm of relating to or encountering other people. That is, the knowledge base that knowledge workers experience in jobs influences the types and intensities of interactions they have, which might be evidenced in their spatially-related choices, namely residential location and commute choices. Two types of spatially-related preferences might be expected: be it more actively orienting towards other people and inhabiting more urban and mixed heterogeneous locations on the one hand, or more preferring isolation from other people and inhabiting low-density, more suburban, and separated homogeneous locations on the other hand.

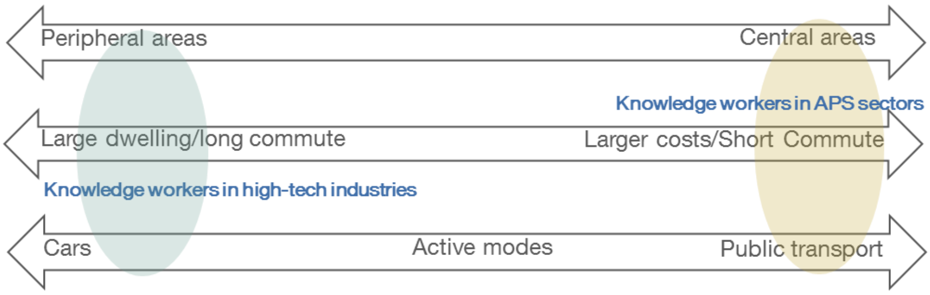


Figure 5. A schematic continuum of spatially-related preferences among workers in high-tech industries and APS sectors.

As shown in Figure 5, on the one hand, workers in APS sectors engage intensively with symbolic or synthetic knowledge (Growe 2011: 15), which has large tacit components (Asheim et al. 2007: 146). Hence, workers in APS sectors are very likely to have a higher demand for face-to-face interactions and might prefer places with diversity or heterogeneity that could provide more stimulation or inspiration. They are relatively accustomed to 'people climate' and might orient themselves more easily when using public transport. Accordingly, workers in APS sectors very probably would focus on factors such as bohemian atmosphere, creative image or atmosphere of tolerance in the process of making their spatially-related choices (Asheim and Hansen 2009: 431). On the other hand, workers in high-tech industries are engaged intensively with analytical or synthetic knowledge with the algorithmic knowledge production mode. Their knowledge creation is relatively less associated with interactions with customers compared to workers in APS sectors, thus they would very probably have smaller preference for encounters with other actors. The role of residence does not penetrate much into their working sphere. Thus, workers in high-tech industries would likely tend to focus on conventional factors such as housing cost, housing ownership, mobility cost, and dwelling size in their choices. Specifically, this study aims to examine the following three hypotheses:

Hypothesis 1: Symbolic and synthetic APS-workers' residential locations tend to concentrate in central areas, whereas analytical and synthetic high-tech workers tend to deconcentrate in relatively peripheral areas.

Hypothesis 2: Symbolic and synthetic APS-workers tend to trade off housing cost for short commutes, whereas analytical and synthetic high-tech workers tend to tolerate long commutes for larger dwelling.

Hypothesis 3: Symbolic and synthetic APS-workers more frequently use public or non-motorized commute modes, whereas synthetic and analytical high-tech workers tend to depend more on cars to reach their workplaces.

These three hypotheses do not stand-alone, instead, there are internal linkages connecting them. Hypothesis 1 focuses on both the process and result of residential moves in the region. The observed evidence is the location, namely one reference point of the commuting trip. Hypothesis 2 focuses on the underlying trade-offs in residential change and provides explanations for the spatial outcomes in Hypothesis 1. Firstly, Hypothesis 3 is also the outcome of residential location in Hypothesis 1 and residential trade-off process in Hypothesis 2. In addition, Hypothesis 3 also provides one explanation for the residential trade-off processes in Hypothesis 2, since different usages of preferred transport modes will influence the threshold of tolerance for commuting length. Last but not the least, the choice of commute transport mode in Hypothesis 3 also indirectly influences the residential choice in Hypothesis 1. Overall, residence location as one end of the commute trip in Hypothesis 1, the process of commuting and the relative importance of commute weighted against other aspects in Hypothesis 2, and the modes of commute in Hypothesis 3 together constitute a comprehensive perspective for investigating the interrelated residence, workplace and mobility choices of knowledge-workers.

Part III RESEARCH METHODOLOGY

5 Research design and methods of analysis

This chapter firstly introduces how the research is designed: including the definition and categorization of the target group, the study area and its spatial-functional structure. Afterwards, this chapter will introduce the research data and the specific methods of analysis including spatial analysis, logistic regression analysis, as well as the preference analysis.

5.1 Definition and categorization of knowledge workers

5.1.1 Definition of target group: knowledge workers

Definition and conceptualization of knowledge workers

'Knowledge-worker' is a term coined by Drucker (1959) in his book 'Landmarks of tomorrow' (Drucker 1959). Knowledge workers are paid for their acquired knowledge rather than their physical labor and manual skills. They are people who 'think for a living' (Cooper 2006: 59). Knowledge workers employ their embodied knowledge as an input factor and create services or products embodying new knowledge. Another characteristic of knowledge workers is that they execute important functions in jobs, performing analytical non-routine tasks such as complex communications, or coordinating project teams. These frequent engagements in interactions facilitate in turn their knowledge creation. However, the traditional human capital approach based on formal education level does not capture exactly these two characteristics of knowledge workers (Johnes 1993; Cohn 1980). Hence, this study uses a functional approach, namely applying two relevant criteria to operationalizing the definition of knowledge workers (Figure 6). The first criterion is that knowledge workers should contribute to knowledge economies by applying their expert knowledge and creating new knowledge, namely they work in knowledge-intensive economic sectors. The second criterion is that knowledge workers should execute complex tasks in their jobs. They employ their abstract cognitive skills to perform complex tasks such as analytical reasoning and complex communications, rather than routine or manual tasks (Autor, Levy and Murnane 2003).

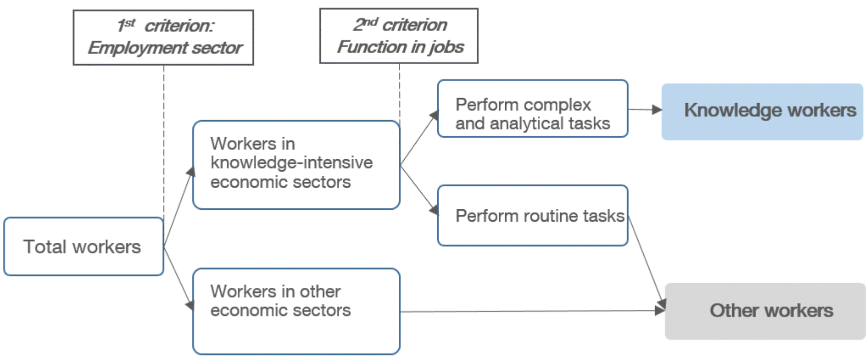


Figure 6.Two criteria to operationalize the definition of knowledge workers.

The first criterion: occupations groups belong to knowledge-intensive sectors

High-tech industries are characterized by a larger share of highly skilled employees, high growth rates, high ratios of research and development investment compared to sales, a worldwide oriented market for products, and a fast change rate of technological progress (Legler and Frietsch 2006: 8; Gehrke et al. 2009: 33; Rogers and Larsen 1984: 29). Advanced-Producer-Services provide specialized services and process specialized information deploying their embodied professional knowledge to other service sectors (Hall and Pain 2006: 4). This study takes its cue from the operationalization of high-tech industries or advanced-producer-services delimited by Thierstein, Goebel and Lüthi (2007: 29) (Table 3). High-tech industries include branches of chemistry and pharmacy, machinery, electronics, computer and hardware, telecommunication, medical and optical instruments, and vehicle constructions. APS sectors include branches of banking and finance, advertising and media, information and communication services, insurance, logistics (3p&4p), management and IT consulting, design, architecture and engineering, law and accounting. The occupation groups of workers are matched with these economic branches. The individually-based web-survey in the study by Thierstein et al. (2016) collects information on people's specific occupation groups at two-digit level, based on the classification of occupations by the federal agency for employment (Bundesagentur für Arbeit 2010) (Question 1 in the appendix). Accordingly, a correspondence table between 2-digit occupation groups (Bundesagentur für Arbeit 2010) and 4-digit economic branches (Destatis Statistisches Bundesamt 2003) is established (Table 12A in the appendix).

Table 3. Specific branches with the corresponding NACE codes in 2003 of high-tech industries and APS sectors in knowledge economy (Legler and Frietsch 2006; Lüthi 2011: 104).

High-tech industries	Advanced-Producer-Services (APS)
Chemistry & Pharmacy: 2330, 2413, 2414, 2416, 2417, 2420, 2441, 2442, 2451, 2461, 2463, 2464, 2466, 2511, 2513, 2615	**Banking & Finance:** 6511, 6512, 6521, 6522, 6523, 6711, 6712, 6713, 7011, 7012
Machinery: 2911, 2912, 2913, 2914, 2924, 2931, 2932, 2941, 2942, 2943, 2952, 2953, 2954, 2955, 2956, 2960	**Advertising & Media:** 7440, 2211, 2212, 2213, 2214, 2215, 9211, 9220, 9240
Electronics: 3110, 3120, 3140, 3150, 3161, 3162, 3210, 3320, 3330	**Information and Communication Services:** 6430, 7221, 7230, 7240, 7250, 7260
Computer & Hardware: 3001, 300	**Insurance:** 6601, 6602, 6603
Telecommunication: 3220, 3230	**Logistics (3p & 4p):** 6030, 6110, 6220, 6230, 6340
Medical & optical instruments: 3310, 3340	**Management- & IT-Consulting:** 7210, 7222, 7413, 7414, 7415
Vehicle construction: 3410, 3430, 3511, 3520, 3530	**Design, Architecture & Engineering:** 7420, 7430
	Law: 7411

The first criterion by itself is insufficient to define knowledge workers. The study further applies a second criterion to capture the characteristic that they fulfill key functions in jobs. To operationalize the function, the four-level scale complexity of activities introduced by the federal agency for employment (Bundesagentur für Arbeit 2010: 26-28) is applied in the web-survey (Question 2 and 2.1-2.4 in the appendix).The first basic level is routine work such as assistant activities ('Helfer' in German); To perform these activities, little or no specific knowledge is required. The second level is specialist-oriented activities. To perform these tasks, specific technical skills are required ('Fachkraft' in German). The third level is complex professional activity, which requires the ability to deal with sophisticated technical and management tasks ('Spezialist' in German). The highest level is highly complex tasks. These activities have a very high degree of complexity and require a correspondingly high level of knowledge ('Experte' in German). For instance, research and development, and leadership and management tasks within a (large) company. Workers who execute complex professional activities or highly complex tasks are regarded as fulfilling key functions in jobs.

The second criterion to define knowledge workers: key function in jobs

To summarize, knowledge workers are those who perform complex analytical tasks in high-tech industries or APS sectors (Berger and Frey 2016; Autor, Levy and Murnane 2003). These workers are endowed with interactive, problem-solving, complex communication, managerial and analytical reasoning skills. This function-based approach is more relevant to the mode of knowledge production, since it better measures about individual cognitive and abstract skills applied in economies, compared to the conventional education-based measure (Glaeser et al. 2004; Becker 1993; Autor, Levy and Murnane 2003). This provides the basic condition for further differentiating them according to specific knowledge base in the following subsection.

Advantage of this function-based approach

The match of the occupation group with the employment sector is not that accurate compared to Growe's (2011: 91-93) approach of matching 3-digit occupation groups defined by the Federal Agency for Employment (Bundesagentur für Arbeit 1988) with 5-digit economic branches of Federal Statistics Office (Destatis Statistisches Bundesamt 1993). Imprecision occurs in the process of matching 2-digit occupation groups (Bundesagentur für Arbeit 2010) with 4-digit economic branches (Destatis Statistisches Bundesamt 2003). According to Bundesagentur für Arbeit (2010), the whole occupation group of 'IT, information and communication technology occupations' was included as synthetic APS-workers. The potential error is that a subgroup of synthetic high-tech workers dealing with telecommunication technology might also be accounted workers in APS sectors. Similar errors also occur in medicine-

Potential errors of the specific procedures in selecting knowledge workers related occupations: although only medical occupations belong to knowledge workers, other general health-related occupations might be also included as knowledge workers. Nevertheless, this will not affect much the major differentiation among broad categories due to the smaller share in total sample (Table 13A in the appendix).

5.1.2 Categorization of knowledge workers according to knowledge base

Using the primary knowledge base to differentiate knowledge workers

Knowledge workers do not form a homogeneous population and they could be further categorized into various subgroups by applying various criteria such as socio-economic characteristics or lifestyle. Nevertheless, since knowledge workers are all characterized by their role in the knowledge economy, the research departs from the perspective of the employee role, aiming to discover the influence of their knowledge-intensive job-related tasks on their spatially-related choices. The key factor used in defining their role as a knowledge worker is the primary knowledge they use for executing the tasks in their jobs. Knowledge base is assumed to generate a significant impact on knowledge workers' spatially-related choices, since it relates directly to the mode of thinking, the contexts in which they are embedded in their daily work, as well as the networks they are involved in. All these aspects drive the decision-making process in choosing residence, workplace location and commute mode (Chapter 3.1). Hence, to understand the rationale underlying knowledge workers' choices of residence, workplace, and commute, knowledge workers are further differentiated according to the primary knowledge base they use. Every knowledge-based activity in occupations actually needs more than one type of knowledge. For instance, software industries apply both synthetic and analytical knowledge bases (Pina and Tether 2016: 404). In the research stage of a product development, analytical knowledge and skills are mainly employed, while in the later development stage, synthetic knowledge and skills needed in optimizing and adjusting the product become more and more relevant. Accordingly, the categorization of knowledge workers into subgroups depends on the dominant knowledge base they use (Growe 2011: 15; Asheim and Hansen 2009: 434; Lüthi 2011: 14). Given that synthetic and symbolic knowledge are equally important for the occupation group 'Planning, architectural and surveying professions (31)', it can be accounted as comprising both synthetic and symbolic APS-workers, which allows us to maintain the comprehensive characteristics of synthetic and symbolic knowledge workers.

Four subgroups of knowledge workers

The final categorization of knowledge workers includes workers using mainly analytical knowledge in high-tech industries (abbreviated: analytical synthetic high-tech workers), workers using mainly synthetic knowledge in high-tech industries (abbreviated: synthetic high-tech workers), workers using mainly synthetic knowledge in APS sectors (abbreviated: synthetic APS-workers), and workers using mainly symbolic knowledge in APS sectors (abbreviated: symbolic synthetic APS-workers). The specific occupations within each group of knowledge workers are presented in Table 4. The sample sizes of analytical synthetic high-tech workers, synthetic high-tech workers, synthetic APS-workers and symbolic APS-workers, and other workers are, respectively, 339, 137, 1073, 252, and 4048. Since the four groups of knowledge workers appear many times, this work refers to them with their abbreviations in the remaining text.

Table 4. Classification of knowledge workers into four subgroups according to two dimensions: the employment sector and the primary knowledge base.

	High-Tech industries	Advanced-Producer-Services (APS)
Analytic knowledge base	Analytical high-tech workers ▪ Technical research development, design and production management occupations ▪ Medical health occupations ▪ Mathematics, biology, chemistry and physics occupations	*Not applicable*
Synthetic knowledge base	Synthetic high-tech workers ▪ Precision optics production occupations ▪ Machinery and vehicle technology occupations ▪ Mechatronics, energy and electrical trades ▪ Professions in medicine, orthopedic and rehabilitation equipment	Synthetic APS-workers ▪ Occupations in business management and organization ▪ Occupations in insurance and financial services, accounting and tax advice ▪ Occupations in law and administration ▪ Planning, architectural and surveying professions ▪ IT, Information technology occupations
Symbolic knowledge base	*Not applicable*	Symbolic APS-workers ▪ Product design and handicraft professions, visual arts, musical instruments ▪ Occupations in advertising, marketing, commercial and editorial media ▪ Planning, architectural and surveying professions

5.2 Study area and its spatial-functional structure

5.2.1 Introduction to the metropolitan region of Munich

The metropolitan region of Munich, with a population of 6.0 million in 2015 (Bayerisches Landesamt für Statistik 2016) covering an area of 26,000 km2, is located in the state of Bavaria in Germany (Figure 7) (Bayerisches Landesamt für Statistik 2016). It is one of the most economically competitive metropolitan regions in Germany, largely owing to its knowledge economy and a highest share (20.1%) of highly qualified employees functioning as the 'engine of innovation' for regional development (Hafner et al. 2007: 40; Goebel, Thierstein and Lüthi 2007: 5). The headquarters or major offices of several global companies such as Siemens, BMW, and Allianz Insurance are located in the region. Excellent universities (Technical University of Munich and Ludwig-Maximilians-University of Munich) and important research institutes such as the Max Planck and Fraunhofer institutes are also located in the region. The city of Munich is the state capital and metropolitan core city with a population of 1.4 million. The second largest city, Augsburg, is located at a distance of 80km from Munich (Hafner, von Streit, et al. 2008). The metropolitan region of Munich has until recently displayed a monocentric structure, since a dominant share of firms, especially those in video and film activities, software firms, and law firms are located in the city of Munich. High job density leads to over-concentration, which also contributes to the recruitment of workers from a wider hinterland (Boussauw, Neutens and Wiltox 2012: 704).

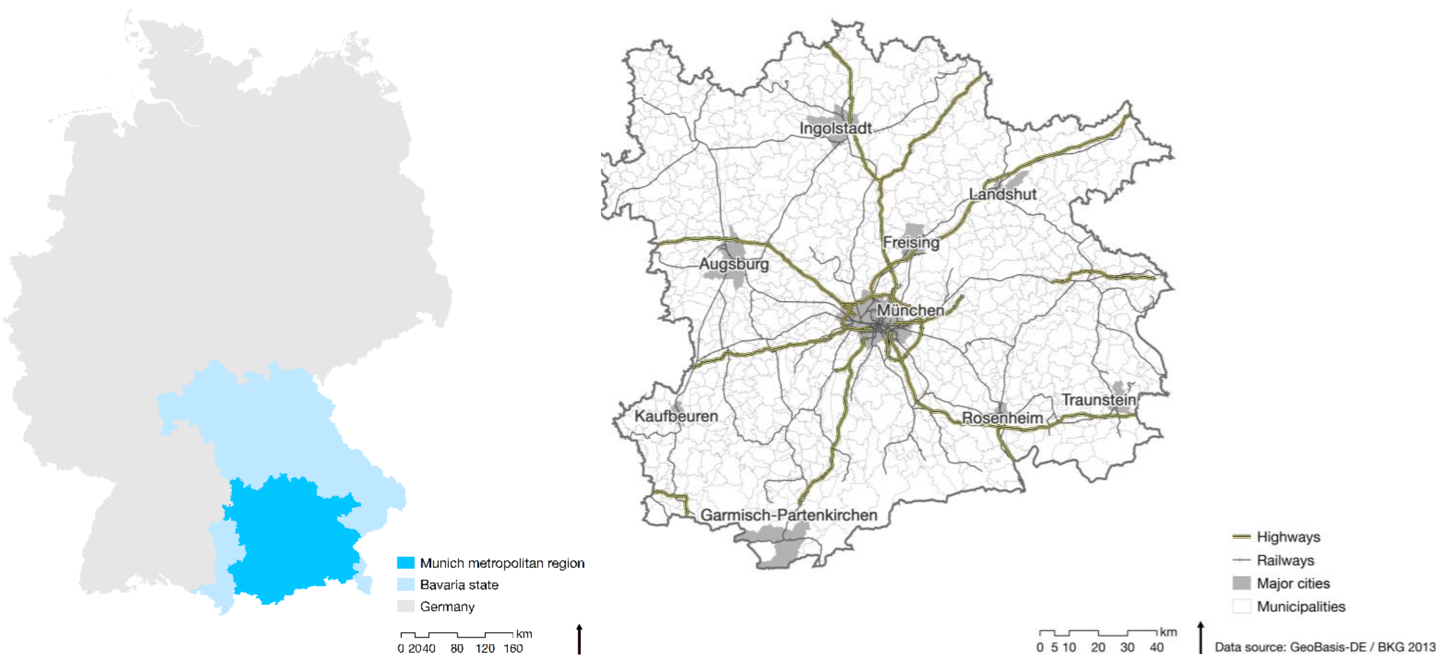


Figure 7. Location (left) and basic spatial structure (right) of the metropolitan region of Munich.

Both the prosperous economy and the monocentric spatial structure contribute to the attractiveness of the living in the region, which implies a tight housing market with high residential costs. This provokes concerns of finding a good residence with reasonable price. 90% of persons surveyed in previous studies regard this aspect worrying. 60% of them find it very worrying (Hafner, Heinritz, et al. 2008: 46). Mobility cultures, on the other hand, are much more public- and active transport friendly. The mixed land use, the good provision of public transport infrastructures in Munich, and the policies of promoting the cycling together guarantee individuals' flexibility to choose between cars and other transport modes (Lanzendorf and Busch-Geertsema 2014; Pucher and Kurth 1995).

5.2.2 Regional structure: morphologically and functionally

A metropolitan region is not only a container of specific functions, but also a process space defined by many functional interdependencies, including social, economic and cultural relations (Thierstein, Förster and Lüthi 2009; Hesse 2010; Amin and Thrift 2002: 63). That is, the spatial structure of a region could be approached und understood both morphologically and functionally (Figure 8) (Burger, van der Knaap and Wall 2014: 820). Firstly, the spatial structure is regarded as a series of areal distributions from a morphological perspective. If most of the population and jobs are concentrated in the core city, the region is characterized as morphologically monocentric. If the population and jobs are also distributed in secondary cities or regional centers, and the overall distribution is to some extent balanced in the space, the region is then characterized as morphologically polycentric. Secondly, it is possible to view the spatial structure as a set of flows among specified locations of the region, namely a 'space of flows' (Castells 1996: 412), beyond viewing the region as a space of place. For instance, trade flows, capital movements, wages and salaries paid by firms to commuters. Since it is not easy to acquire data on these flows, surrogate flows such as shopping trips, freight traffic, commuter flows or telephone calls are used instead. When the flows are all towards the core city in the region, the region is functionally monocentric. When the flows between secondary cities or the flows originate from the core city towards other cities, the region is by implication functionally polycentric. A polycentric region consists of several urban centers; each has one or more specializations without any dominance over the other, forming a well-developed pattern of interactions among the centers. The following section will firstly analyze the region using spatial distribution data and secondly from using commute flows.

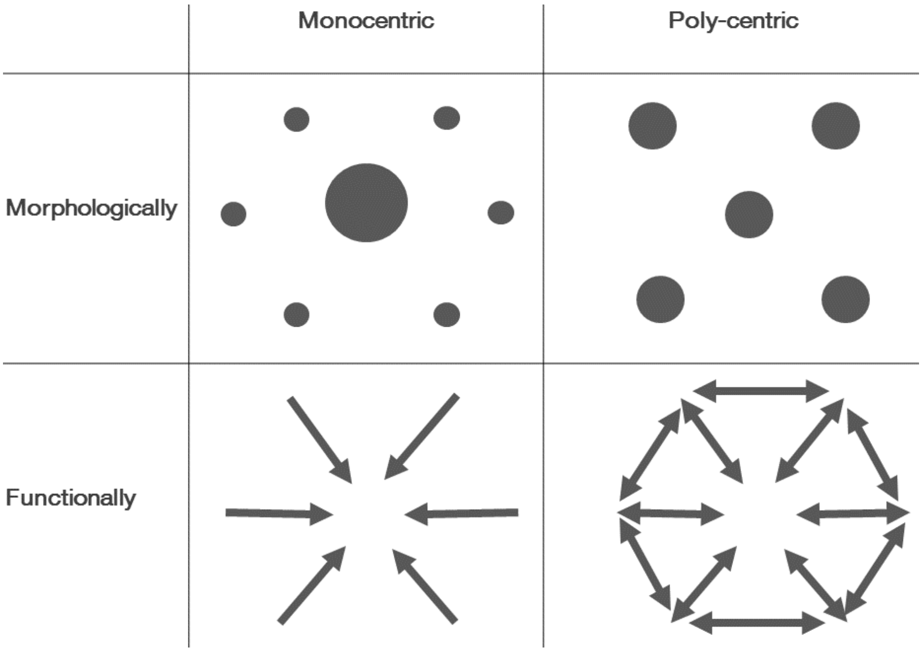


Figure 8. Morphological poly-centricity versus functional poly-centricity [Modified according to Burger, van der Knaap and Wall (2014: 820)].

Morphological perspective: the distribution of jobs and residents measured by the 'job-housing ratio'

To better understand the distribution of employment and housing as well as the balance between these two functions from a morphological perspective, the indicators of job-housing ratio is applied. The job-housing ratio is the ratio between the number of jobs localized in a spatial unit and the number of working people who live in the same spatial unit (Boussauw, Neutens and Wiltox 2012: 692). It is calculated in Formula (1), where B is the job-housing balance ratio; T is the number of jobs that are compulsory for social insurances and W is the number of total employed people who live in that place. The ratio between 0.8 and 1.2 is considered as demonstrating a balance between employment and housing within the place. The ratio below 0.8 indicates that there are more employed residents than job opportunities in a region; the ratio above 1.2 indicates that there are more job opportunities than that of employed residents in the region. Both cases are associated with a relatively longer average commuting duration (Boussauw, Neutens and Wiltox 2012: 702).

$$B = \frac{T}{W}, \qquad (1)$$

It is observed that the major cities and municipalities neighboring them do not have a balanced ratio between housing and job (Figure 9). The largest job-housing ratios appear both in the core city and in secondary cities. In other words, most job opportunities are concentrated within the main cities in the region. In contrast, most of the residential population are concentrated in the neighboring districts (lower job-housing ratio).

The catchment areas of these labor markets in major cities are extended beyond these cities and a segment of the workers commute to these cities daily or weekly.

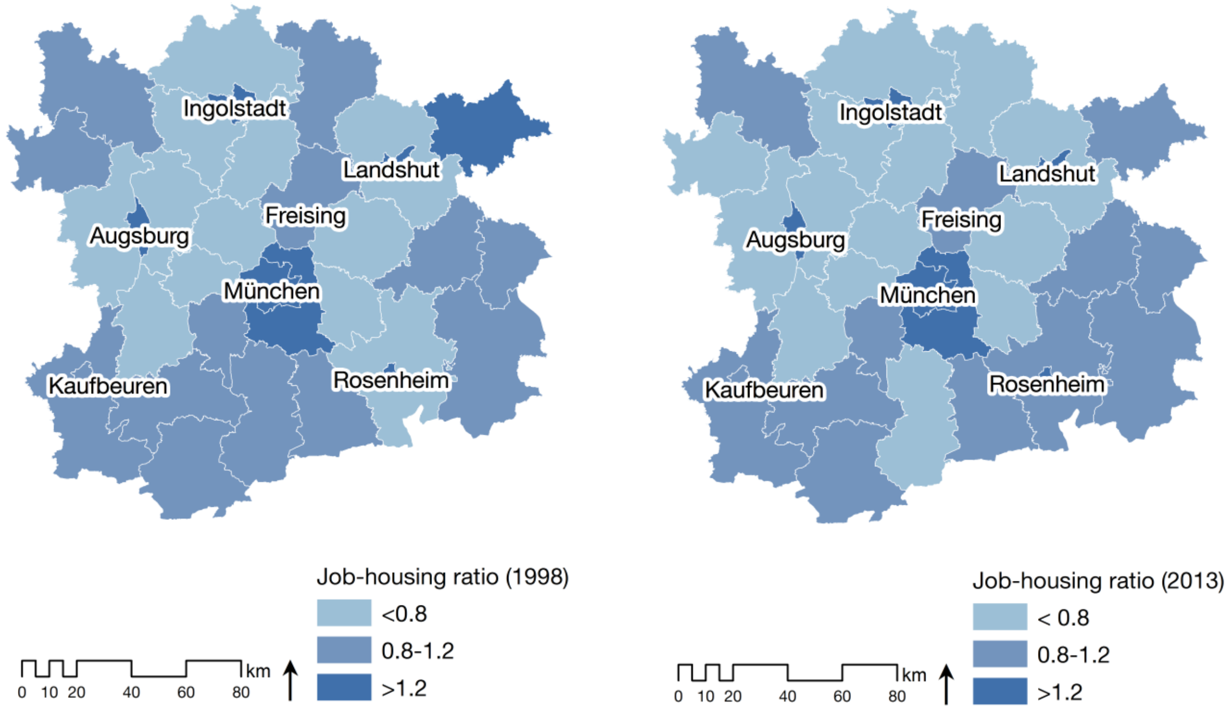


Figure 9. Job-housing ratio of each district within the metropolitan region of Munich [Modified according to Zhao, Bentlage and Thierstein (2016: 111); Data source: Bayerisches Landesamt für Statistik (2015)].

Functional perspective: The relative importance of employment and residential function measured by 'in-/out-commuting ratio'

Regarding the functional structure, the in-commuting and out-commuting ratio and the commuting intensity are applied to measure the commute flows between each municipality and district. The in-commuting and out-commuting ratio is calculated according to Formula (2), where R is the ratio of in- and out- commuting share, Si is the in-commuting share and So is the out-commuting share to an area, I represents the number of in-commuters and O represents out-commuters. T is the number of jobs and W is the number of total employed people who live in the same region. If R is smaller than 1, the residential function is more prominent than the employment function; if R equals 1, the employment function is as important as the residential function; if R is greater than 1, the employment function takes precedence over the residential function in the region (Zhao, Bentlage and Thierstein 2016).

$$R=\frac{Si}{So}=\frac{I/T}{O/W} \quad (2)$$

Additionally, when the in-commuting and out-commuting ratio is also applied to the level of municipality, similar results regarding the spatial structure are found. Figure 10 shows that the employment function was much more apparent compared to the residential function in the city of Munich in 1998. In contrast, while the residential function gained importance in Munich, the employment function gained importance in other municipalities in the region in 2013. The employment and residence concentration became more balanced from 1998 to 2013 (Zhao, Bentlage and Thierstein 2016).

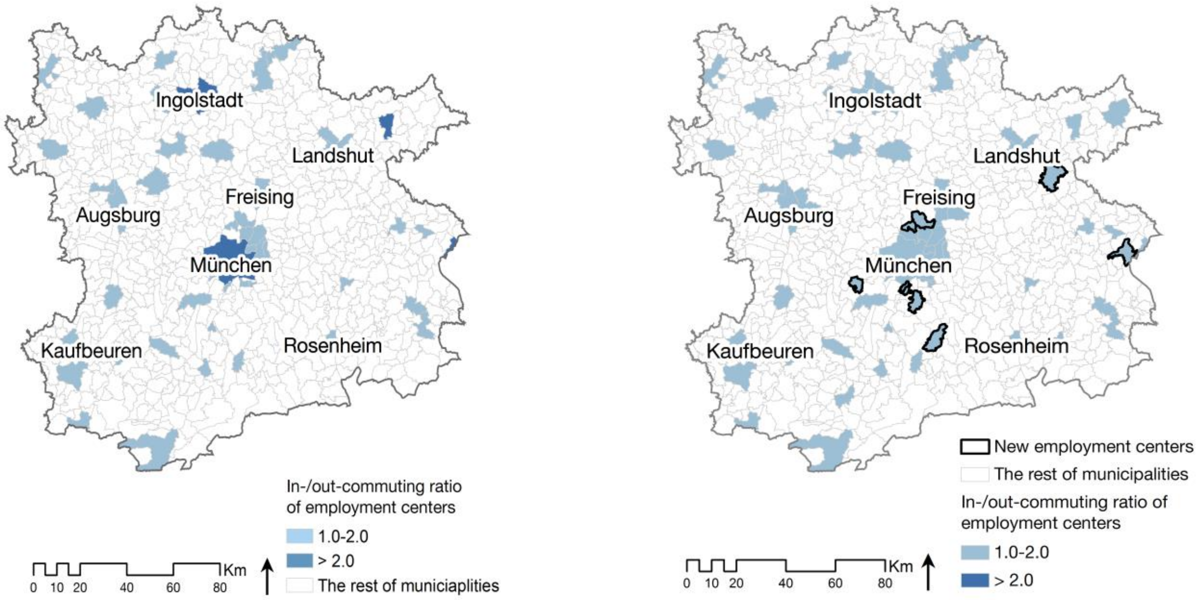


Figure 10. In-commuting and out-commuting ratio of each municipality within the Munich metropolitan region in 1998 (left) and 2003 (right) [Modified according to Zhao, Bentlage and Thierstein (2016: 110); Data source: Bayerisches Landesamt für Statistik (2015)].

Functional perspective: commuting flows measured by the 'commuting intensity'

In addition, the overall commuting dynamics of the labor market at the district level are calculated with Formula 3, which is defined by Guth et al. (2011: 21). It represents the commuting intensity. The meanings of I, O, W, and T are as same as in Formulas (1) and (2).

$$I_n = \frac{I+O}{W+T} \tag{3}$$

From 1998 to 2013, the commuting intensities of those districts that are between the city of Munich and the secondary cities increased (Figure 11). Two underlying processes appear to be shaping the functional structure: firstly, more people accept long commutes for better job opportunities in large cities (Boussauw, Neutens and Wiltox 2012: 690) and the catchment area of Munich city has been enlarged. Secondly, due to the relocation of knowledge-intensive firms in their established stages further from the city of Munich, those neighboring districts are also providing job opportunities that attract people from the neighboring districts. Thus, the number of in-commuters to these districts increases and subsequently the commuting intensity also rises. The metropolitan region of Munich is therefore evolving from a monocentric region towards a functional polycentric region.

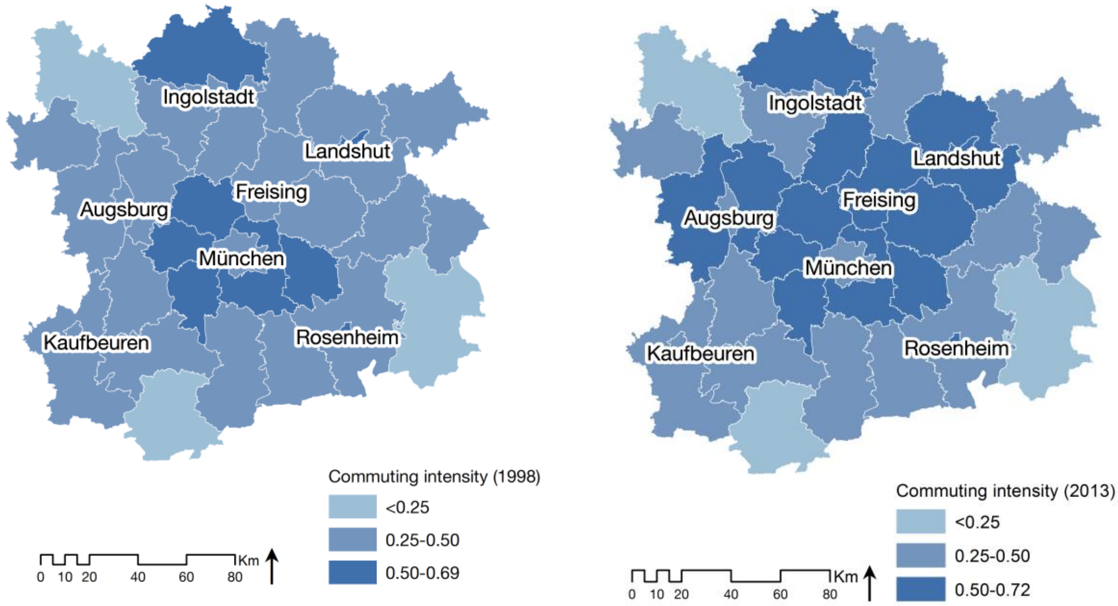


Figure 11. The commuting intensity within each district in the Munich metropolitan region [Modified according to Zhao, Bentlage and Thierstein (2016: 112); Data source: Bayerisches Landesamt für Statistik (2015)].

5.2.3 Spatial-functional structure and the concept of 'central areas'

A spatial-functional structure is necessary to study spatially-related choices

Individual spatially-related choices such as choice of workplace, residence, and commuting mode are not confined to the territorial-administrative delimitations. Hence, a spatial-functional differentiation of areas in the region is necessary to better understand individual spatially-related behaviors. The existing spatial-functional structure of the Munich metropolitan region defined by Thierstein et al. (2016) consists of five categorizations (Figure 1A in the appendix), namely centralized urban areas, decentralized urban areas, city catchment areas, residential areas with tourist attractions, and peripheral areas (Thierstein et al. 2016: 29). This spatial-functional typology is based on aspects including settlement structure, services, accessibility to workplaces and population, residential costs, building types, and share of vacation apartments, which function as the points of reference for the spatial-functional categorization in this study. Gravity-based accessibility is a generalization of the population-over-distance relationship or population potential concept develop by Stewart (1948) and measures the intensity of interaction possibilities rather than just measuring the ease of interaction (Hansen 1959: 73). It calculates the potential number of workplaces and population that can be reached with a certain mode of transport(Thierstein et al. 2016).

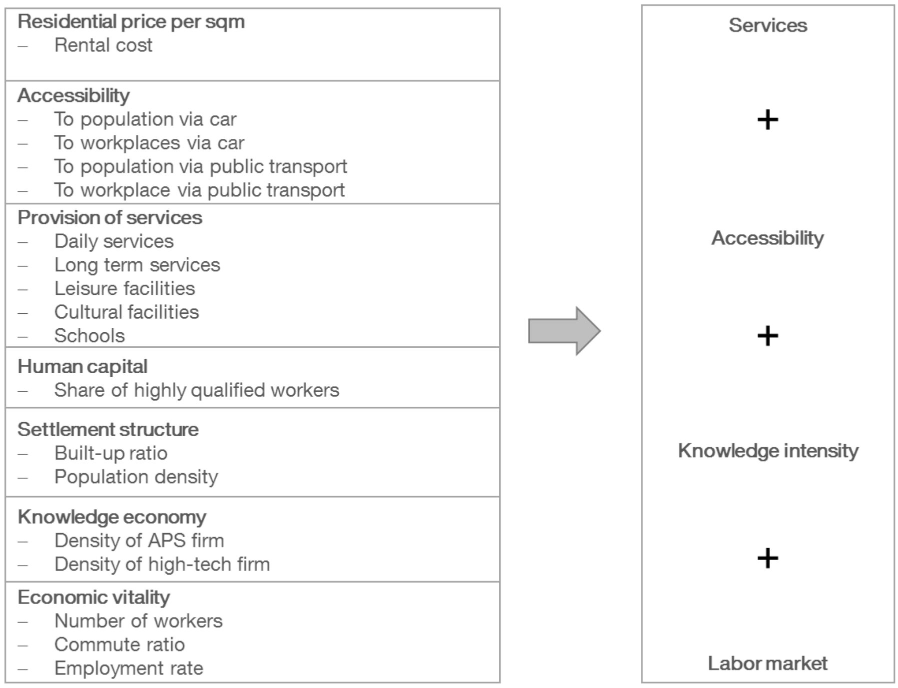


Figure 12. Aggregation of 18 indicators on seven dimensions to four major components with principle component analysis.

Spatial-functional structure of the region: five clusters

This study categorizes the region into several spatial-functional clusters using the following procedures. Firstly, indicators used in the afore-mentioned reference spatial-functional categorization are adjusted. On the one hand, indicators that are not highly relevant to the research objective are deleted. For instance, the percentage of holiday or second homes of total number of residences, percentage of residences occupied by owners of total number of residences, and percentage of residences rented for occupational purposes (including rent-free) of total number of residences. On the other hand, relevant indicators such as the density of high-tech and APS knowledge-intensive firms, the employment rate, and share of highly qualified workers have been added into the system of indicators. Overall, the index consists of 18 indicators on seven dimensions: residential rental cost per square meter, accessibility, provision of services, human capital, settlement structure, knowledge economy, and economy vitality (Figure 12). A detailed list of the indicators with their sources is in Table 14A in the appendix. All indicators are available at the scale of municipality group ('Gemeindeverband' in German), except the share of highly qualified workers that is available only at the district scale. To guarantee the consistency of the spatial resolution of the data, the same share of highly qualified workers at the district scale is assigned to municipalities within the common district. In other words, each municipality 'inherits' the same value from the district that it belongs to. This simple processing is reasonable, since the share of highly qualified workers is assumed to be strongly relevant in residential choices of knowledge workers, which differentiates the current level of human capital among districts. Based on this differentiation, all other 17 indicators will further serve to spatially and functionally categorize individual municipalities. Secondly, a principle component analysis in SPSS is applied to condense the afore-mentioned 18 indicators. Four major components, namely services, accessibility, knowledge intensity, and labor market, which account for 78.7% of the total variances, have been extracted (Table 15A in the appendix). Thirdly, based on these four components, a cluster analysis using the ward method is applied to differentiate the region into five spatial-functional clusters: knowledge intensive and well-accessible metropolitan core, city catchment areas with good accessibility, areas with relatively good services, peripheral areas, and secondary cities with good services and high employment rate (Figure 13). The ward method is chosen since it differentiates better between spatial entities, maximizing the similarities within each cluster and the dissimilarities between different clusters. Fourthly, three spatial-functional clusters, namely knowledge-intensive and well-accessible metropolitan core, city catchment areas with good accessibility, and secondary cities with good services and high employment rate are defined as 'central municipalities', since they achieve the highest score on at least one of the four components (Table 16A in the appendix).

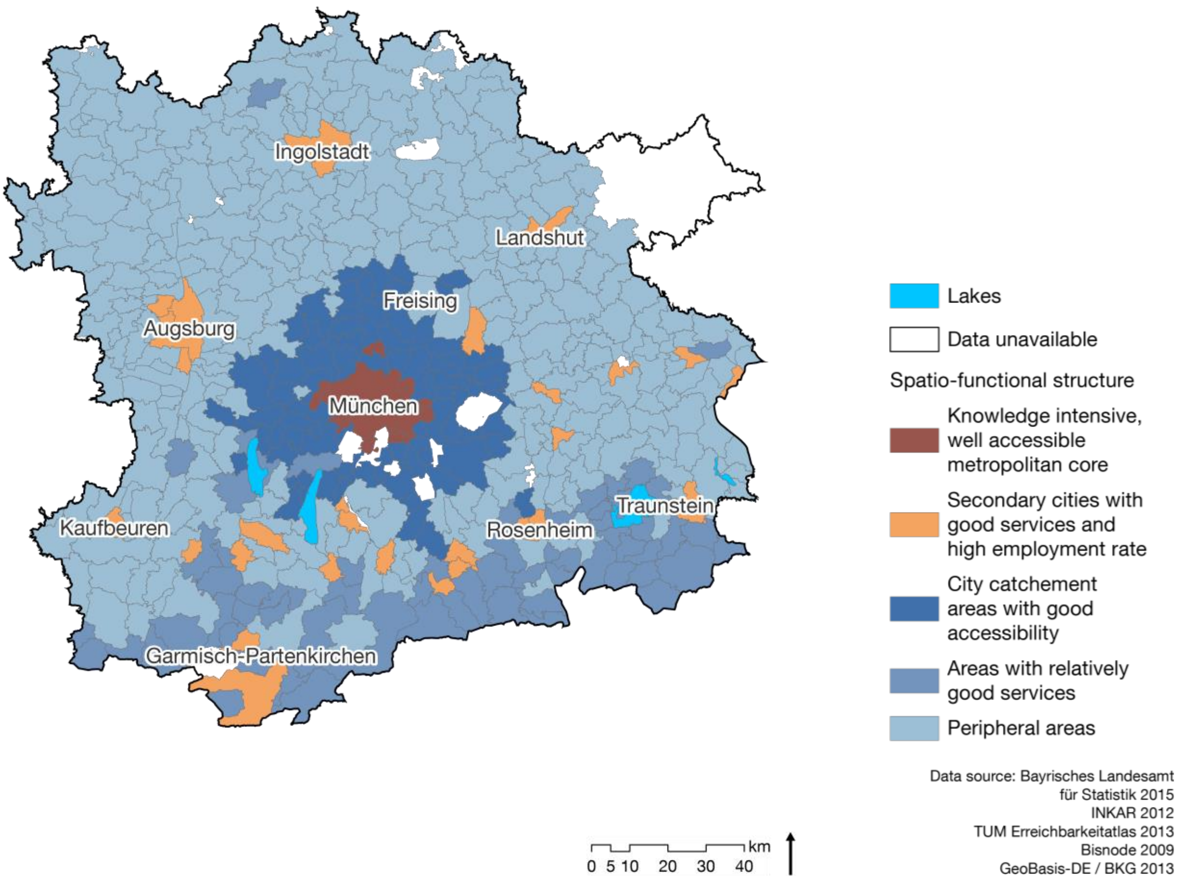


Figure 13. Spatial-functional structure of the metropolitan region of Munich

Definition of central areas vs. non-central areas in the region

Finally, considering that residential choice is also sensitive to different neighborhood environments within one municipality, 'central municipalities' are further refined by selecting out only areas that lie within less than 1000m of public transport stations, which are defined as 'central areas' (Figure 14). The remaining areas of the region are defined as 'non-central areas' or 'peripheral areas'. Public transport stations, including only rail or subway stations, are chosen, since they are important activity nodes and function as centers of neighborhoods. 1000m is the maximal distance that a person would normally accept when walking to the transport station, and used as the largest radius of the catchment area of the transport station (Cervero and Day 2008: 14). Since the individual choice between central and peripheral areas is the main objective, areas between close vicinity (less than 500m) and secondary vicinity catchment areas (between 500m and 1000m) will not be further differentiated. Thus, whether each location is located within or outside of 'central areas' can be determined based on their geographic coordinates.

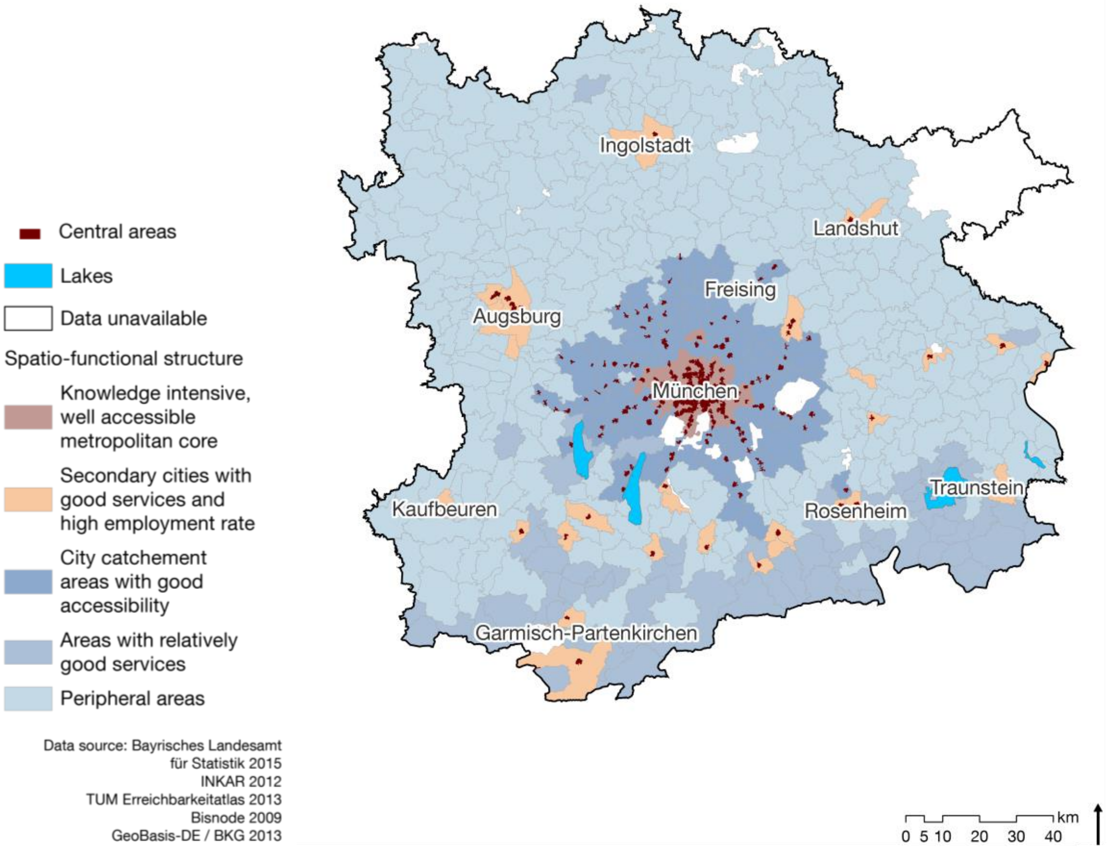


Figure 14. Distribution of 'central areas' in the metropolitan region of Munich with the five spatial-functional categorizations as the background.

5.3 Data and methods of analysis

5.3.1 Research data

Integration of various types of data

Various types of data are integrated in this study (Figure 15): Firstly, to understand the spatial-functional structure of the region, the structural statistical data such as population and employment (Bayerisches Landesamt für Statistik 2015), the average residential rental cost per square meter (Immobilien Scout GmbH 2014). In addition, data on knowledge-intensive firms using the data base of Bisnode (2014) is also collected. This data set provides georeferenced firm-level information on firm locations, sectoral classification and employment. In total, 18 indicators on seven dimensions are collected in order to understand the region. Apart from the statistical data, to study individual spatially-related preferences and choices, information on individual residential, workplace locations and commuting modes are collected via web-survey. Only individuals who moved their residence and/or workplaces within the last three years (2011-2014) were invited to participate the web-survey. The basic assumption is that individuals who moved within last three years could clearly remember their decision-making processes and are more likely to fill the information in the survey. This to some extent guarantees the accuracy of their answers and in turn the reliability of the results of analysis. Secondly, along aside the actual choices of residence, workplace and commuting mode, the survey also asked respondents to assess the importance of each attribute at or near residence or workplace location using a four-point Likert scale, namely important, rather important, rather unimportant, or unimportant. Thirdly, based on the geographical locations of their residences and workplaces these positional data in the survey, the accessibility to the workplace, shopping facilities, leisure and cultural facilities for each residence could be also calculated. Lastly, apart from information regarding current situation, data regarding previous situations before moving residences and/or changing their jobs are collected in parallel. For residential choice, data on residential alternatives during the search process are also contained in the survey. In the end, 7,302 respondents participated in the web-survey and among them there were 1,778 knowledge workers (328 analytical synthetic high-tech workers, 242 symbolic APS-workers, 1,029 synthetic APS-workers, and 140 synthetic high-tech workers). The distribution of residential location, job location, commuting mode, income level, household type, mobility resource, and mobility preference among each subgroup of knowledge workers and other workers are presented in Chapter 6 and 8. These socio-demographics and spatially-related choices of knowledge workers are additionally presented in Table 17A in the appendix.

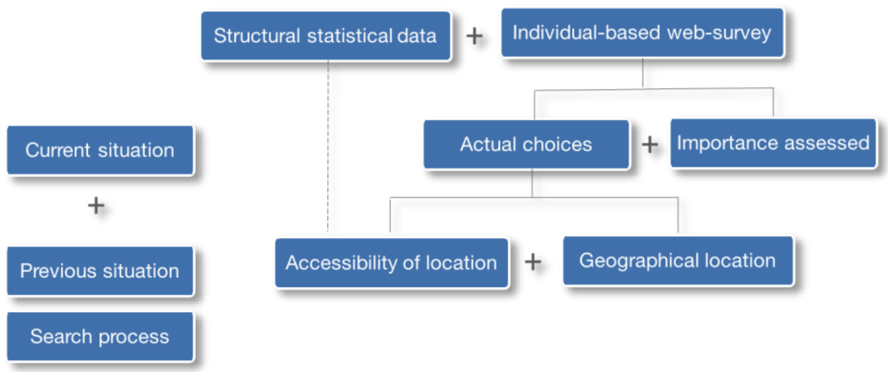


Figure 15. Integration of various types of data in the study.

Suitability and limitation assessment of web-survey data

On the one hand, the web survey was designed to cause the minimal disturbance to the interviewee in terms of its time and location flexibility. The good internet service in the region guarantees access to target group, since it is assumed that knowledge workers in most cases have the access to the internet. On the other hand, the representativeness of respondents needs to be examined regarding the reliability of the results. There are two types of data representativeness in total: socio-demographic representativeness and spatial representativeness. Regarding socio-demographic representativeness, people in the age group between 35 and 45 with employed status may be over-represented. This might be due to their frequent usage of the internet. Another possible explanation would be their higher residential mobility due to the change of household size and income situation. Because there is no available statistical data on population in the age group between 35 and 45 with employment status and moved residences and/or changed jobs, as well as the public/private sector during the survey period, socio-demographic representativeness cannot be adjusted. Regarding the spatial representativeness, the city of Rosenheim is overrepresented, since the target group is better accessed via a cooperation with the city administration in Rosenheim. The study applies a spatial expansion factor as the weight for each individual respondent to reduce the disturbance of spatial over-representativeness. To calculate the spatial expansion factor, the number of total immigrants in the municipality in 2014 is divided by the number of respondents from that municipality. The larger the number of the respondents from a municipality, the less weight each individual respondent is accorded. Since the number of total immigrants is only a proxy for the unknown total sample of the target group (those who moved residences and/or changed their jobs), this spatial expansion factor cannot completely solve the spatial over-representativeness problem. Nevertheless, the data after the adjustment with the expansion factor does represent better for the population who have recently moved.

5.3.2 Spatial analyses: investigate spatial distribution

Spatial analyses including service area analysis, spatial join and buffer analysis, as well as the kernel density analysis are all conducted in the ArcGIS 10.5 platform. Firstly, the analysis of the catchment areas of public transport stations is based on the service area function in the network analysis in ArcGIS. The road networks in 2009 are input as the network dataset. The threshold of the radius is set as 1000m. Setting the route as 'to the facility' or 'from the facility' does not matter, since the 1000m distance threshold is chosen based on the acceptable distance by walking.

Secondly, spatial join and buffer analysis is used to calculate the number of services near each spatial location. The distance threshold for daily shopping and services is set respectively as 500m; the distance threshold for long-term shopping and services, cultural and gastronomic services, and other leisure services is 1500m. The services that are within 500m or 1500m catchment areas of the spatial location will be included as the accessible services, which is based on the function that "target layer is completely within the source layer" in ArcGIS. 'Target layer' refers to the geographical coordinates of services and 'source layer' is the buffers or catchment areas of each spatial location such as residence or workplace.

Lastly, to measure the spatial distribution and concentration of residential locations, kernel density is applied. Kernel density measures the density of features in a neighborhood that surround these spatial features. The kernel density function is based on the quadratic kernel function described by Silverman (1986), whose search radius is set as half of the mean distance among each two points in the surface (Silverman 1986: 76). The density at each output raster cell is the summed values of all the kernel surfaces intersected at the raster cell center. Kernel density considers the information of the relation between each point via the search radius, thus better representing the concentration degree of the spatial features compared to point density analysis.

5.3.3 Logistic regression: model discrete choices

Apply binary logistic regression to model residential location choice

To test the first hypothesis, whether the category of knowledge workers could explain their residential location choice should be examined. Since residential location choice is a discrete choice, logistic regression is applied. Considering that the dependent variable is binary categorical, namely residence located within central areas, or outside of central areas, binary logistic regression is applied. A dummy variable 'residential centrality' is created, when residence is located within the 'central areas', the residential centrality is coded as 1; otherwise the residential centrality is given a value of 0. Logistic regression is a special case of the generalized linear model, and allows the linear model to be related to the dependent variable via a link function (Formula 4).

$$Z=\log(\text{odds}) =\log(p/(1-p))=B_0 + B_1 * X_1 + \ldots + B_n * X_n \quad (4)$$

Z is the log odds of an event, also called logit. P is the probability that an event occurs, here referring to the likelihood of living in central areas. B0 is the constant, B1 to Bn represent the estimation coefficients. X1 to Xn are independent variables. At the beginning, household type, gender, education level, car ownership, income level, and the job location as the control variables are included. Table 18A in the appendix lists the categories, descriptions as well as distribution of the dependent and independent variables. Afterwards, the investigated variable is also included, along with the category of knowledge workers (analytical high-tech workers, synthetic high-tech workers, synthetic APS-workers, symbolic APS-workers, and other workers). Although any subgroup of knowledge workers could be selected as the reference group in principle, synthetic high-tech workers with relatively apparent behavioral characteristics are selected as the reference group to facilitate the interpretation of regression results. In other words, other knowledge worker groups are compared to synthetic high-tech workers (see section 4.1 and 4.2). This is due to following two considerations. Firstly, existing empirical studies obtain consistent findings on the spatially-related revealed preferences of these workers (Asheim and Hansen 2009; Spencer 2015). Secondly, synthetic high-tech workers attach more importance to car-friendly residential locations but less importance to locations with the good access to public transport or daily services compared to all other groups of workers in our web-survey. Most independent variables are directly available from the survey data, while others need further transformation. For better interpretation, the 10 categories of income levels are aggregated into three broad categories: low-income level (less than 2000 Euros per month), medium income level (2000-4000 Euros per month), and high-income level (greater than 4000 Euros per month). Respondents who stated only the importance of car-friendly travel rather than any other modes at the residence are defined as individuals with auto affinity. A dummy variable of auto affinity is constructed, either yes coded as 1, or no coded as 0. Education level has been aggregated into a two-category dummy variable, either with a university degree coded as 1, or without a university degree coded as 0.

$$\text{Odds}=\text{Exp}(B_0 + B_1 * X_1 + \ldots + B_n * X_n) \quad (5)$$

The coefficients for the aforementioned independent variables are calculated with the maximal likelihood estimation, which predicts the occurrence of the event for each individual case. Based on Formula 5, the odds of an event is calculated in Formula 2. For continuous variables, Exp(Bn) represents the factor by which the odds change for a one-unit change in the independent variable. For categorical variables, Exp(Bn) is the odds ratio of when Xn is at a certain category compared to the reference category. If Bn is postive, namely Exp(Bn) is larger than 1, it indicates that the independent variable has a positive influence on the odds of the event. If Bn equals 0, namely Exp(Bn) equals 1, the independent variable has no effect. If Bn is negative, namely Exp(Bn) is less than 1, then the independent variable decreases the odds of the event. In addition, it is also necessary to know whether the odds ratio associated with the socio-demographic characteristics of individuals varies among different groups of knowledge workers. For instance, whether synthetic high-tech workers' residential choices have different sensitivities to the change of household type or income level. Accordingly, logistic regression with the same independent variables (except the categorical variable of knowledge workers) for five groups respectively is applied.

Apply a multinomial logistic regression to model the choice of commute transport mode

To test the second hypothesis, the study further examines whether the category of knowledge workers could explain the dependent variable, namely the commuting transport mode. Since commuting transport modes are differentiated into car, public transport, and active modes – including cycling and walking –a multinomial logistic regression is applied to these three categories. The multinomial logistic regression consists of two binary logistic regressions, where car commuting is set as the reference category: the first part is to predict the odds ratio of using public transport compared to car; the second part is to predict the odds ratio of using active modes compared to car. Apart from the aforementioned independent variables in verifying the first hypothesis, five additional variables have been further included: the residential centrality, the commuting distance, the ratio of the travel time using public transport versus car, and the stated importance of car-friendly travel at the workplace and residence respectively. The commuting distance, the shortest distance between the workplace and residence along the road network, is calculated using the network analysis in ArcGIS. The commuting time with public transport is calculated according to the time schedule provided by the Munich Transport Association (Münchner Verkehrs- und Tarifverbund). The commuting time with car is calculated based on open street map. The stated importance of car implies that respondents mentioned the importance or relative importance of car-friendly travel.

Apply a multinomial regression to model individuals' joint choice of residential location and commute transport mode

Residential location and commute mode choice are interrelated with each other. After the separate modelling of these spatially-related choices, a joint choice of residential location and commute mode is further applied. The dependent variable has six categories: central residential location and commute with cars; central residential location and commute with public transport; central residential location and commute with active modes; peripheral residential location and commute with cars (reference category); peripheral residential location and commute with public transport; peripheral residential location and commute with active modes.

Robustness test with bootstrap algorithms

Lastly, the robustness of the regression results is tested using bootstrap algorithms in SPSS. By randomly selecting 1000 subsamples, it assesses the estimates' accuracy via variance estimation, and produces the confidence intervals and p-values. The bootstrap test results are presented in Table 19A-21A in the appendix.

5.3.4 Revealed and stated residential preferences

Revealed preference approach

Revealed preferences are tastes that rationalize empirically observed actions of the economic agent. People's choices are firstly observed and recorded, these observed actual choices indicate the agent's preferences, and suppose they are compatible with the objective of optimization (Levin and Milgrom 2004: 7). In other words, "we know what people want by observing what they have done" (Storper and Manville 2006: 1263). For instance, if a large proportion of people reside in large-size housing and drive frequently, the conclusion is that the dominant preference for land use and transport is large-plot housing and car-dependent mobility preference. This also holds true for detecting the preference for good accessibility among people who live in multistory apartments in inner urban areas and frequently use public transport or cycling and walking (Storper and Manville 2006: 1263). The limited number of sample workers in each subgroup of knowledge workers restricts the use of the logistic regression model based on each individual decision-making process. Alternatively, an approach of aggregated revealed preference is applied. Aggregated behavior contains useful normative information, which implies the central tendencies of normative preferences for a group. Even though it is inappropriate to assume that people behave similarly to their peers, aggregate revealed preferences may serve as useful defaults (Beshears et al. 2008: 1792). In general, the efforts that individuals are willing to make in choosing certain attributes are approximated as their preference. Specifically, the share of individuals in making efforts to improve certain attributes are used to represent the level of preference in this study.

Stated preference approach

However, the revealed preference approach is not always reliable, since some latent preferences (also belonging to individual actual interests) cannot be realized in certain situations such as passive choice, limited personal experience and intertemporal choice during the transition phase (Beshears et al. 2008; Azevedo, Herriges and Kling 2003). For instance, people who prefer good accessibilities have to accept a residence located in the suburbs if they cannot afford residences in inner urban areas. Residents living in suburban areas may actually also prefer to drive less; however, this preference cannot be manifested since their choice of driving is bounded to their preference for more space (Myers and Gearin 2001: 639). The stated preference approach is another way to detect the normative preference of individuals. The stated preferences approach rationalizes the choices and tastes of individuals when they face several hypothetical alternatives. Although the web-survey does not contain information regarding choices in hypothetical scenarios, individuals are asked to directly assess the importance of each residential attribute. The stated preference approach can discover individual preferences more comprehensively than the revealed preference due to the relatively flexible boundary of choice.

Combining revealed and stated preference approach

To better understand the normative preference (namely the actual interests) of a consumer, the revealed preference and stated preference approaches should be combined (Beshears et al. 2008; Azevedo, Herriges and Kling 2003). Specifically, revealed preferences via analysis of observed choices are compared to respondents' assessment of the importance of certain attributes, which will result in three possible scenarios: if the revealed preferences correspond with their assessment of importance, actual interest can be confirmed, meaning that these individuals have a great willingness to improve the attribute. If revealed preferences are not mentioned in their subjective assessment of the importance, the results of analysis must be tentatively interpreted, since they might indicate a 'dissonance' preference, namely bundled to their primary preference for other attributes. If certain attributes assessed as important are not reflected in the observed choices, it implies that those attributes are of minor importance for them. In other words, it is not their priority preference. Nevertheless, this latent preference might be realized, once the boundary of choice becomes less restrictive.

Part IV RESEARCH FINDINGS

6 Residential location choices of knowledge workers

This section will begin by analyzing both individual and aggregated commute patterns. It continues by presenting the spatial distribution of residential locations as well as the spatial behavior changes associated with the residential move. In addition, it will also report the results of modelling the residential location using logistic regression. This chapter will end with a summary of key findings regarding the residential location choices of knowledge workers.

6.1 Spatial proximity between residence and workplace location

Firstly, individual commute paths in the region serve as the starting point for gaining an overview of the spatial distribution of residences and workplaces as well as the spatial proximity between these two locations. Following this, the commute patterns are shown in an aggregated way, including the commute distance by category, the aggregated commute patterns with reference to the spatial-functional categories, as well as the abstract commute path. Lastly, the changes in job-housing proximity are presented.

6.1.1 Individual commute path between workplace and residence

This analysis focuses on individuals who changed at least one of those two commute ends (residence and workplace) between 2011 and 2014. To better track the changes of the commute paths underlying the regional labor market, only individuals who had previously already worked and resided within the region are included in the analysis. As shown in Figure 19-23, individual commute paths are in general more radical than tangential in form. This is as expected, given that there is a strong concentration of job opportunities within the city of Munich and its neighboring municipalities, accompanied by a concentric form of motorized and public transport infrastructures. In addition, it is difficult to observe apparent changes in terms of individual commute paths between the previous and current state (Figure 2A-6A in the appendix), since there have been no fundamental changes in terms of transport infrastructures and/or an apparent dispersion of job opportunities within the short period of three years.

Comparing knowledge workers as a whole with other workers

When focusing specifically on the commute paths in the current situation (Figures 16-20), it is revealed that all groups of knowledge workers predominantly connect with the city of Munich, either workplace or residence. In contrast, among other workers, the commute between peripheral areas and regional secondary cities such as Augsburg, Ingolstadt, Landshut exist in parallel with commutes connected to the city of Munich. This corresponds with the finding that less-skilled workers are more sensitive to local employment compared to highly skilled workers (Watkins 2016: 16). Other workers have a greater chance of finding job opportunities at the regional centers closer to their residences compared to knowledge workers. Nevertheless, the share of commute paths of other workers between secondary cities and peripheral areas is still much less than the commute paths connecting with the city of Munich. According to Burger's (2014) sketches on functional monocentric and polycentric regions, the metropolitan region of Munich is still relatively functionally monocentric based on the spatial pattern of commute paths (Burger, van der Knaap and Wall 2014: 820).

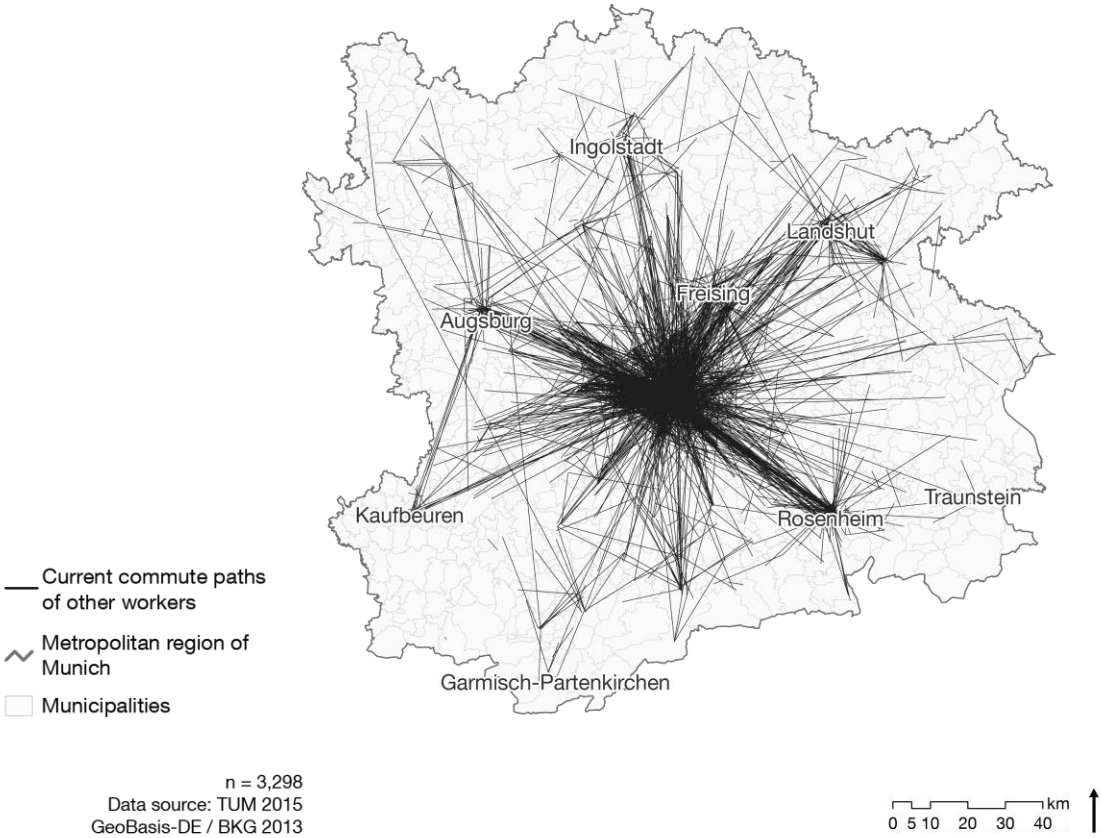


Figure 16. Current commute paths of other workers in MMR.

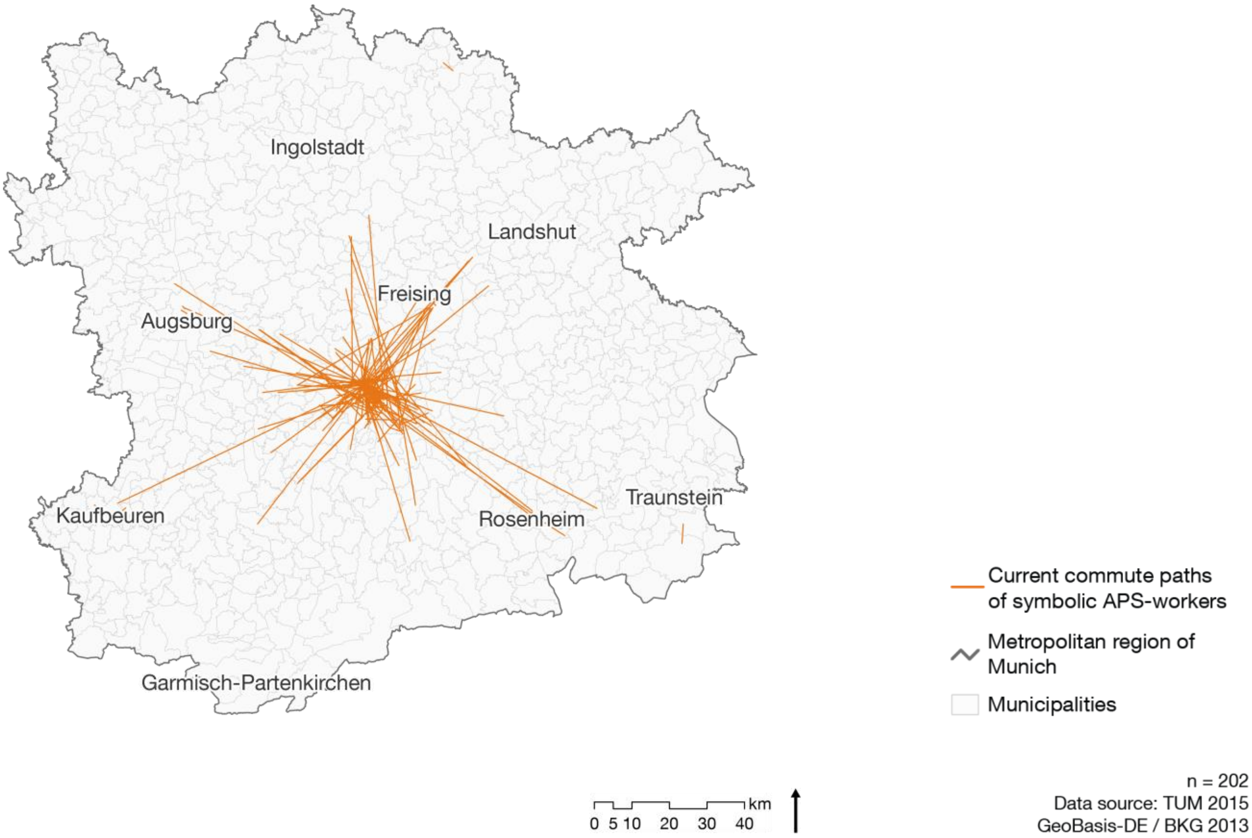


Figure 17. Current commute paths of symbolic APS-workers in MMR.

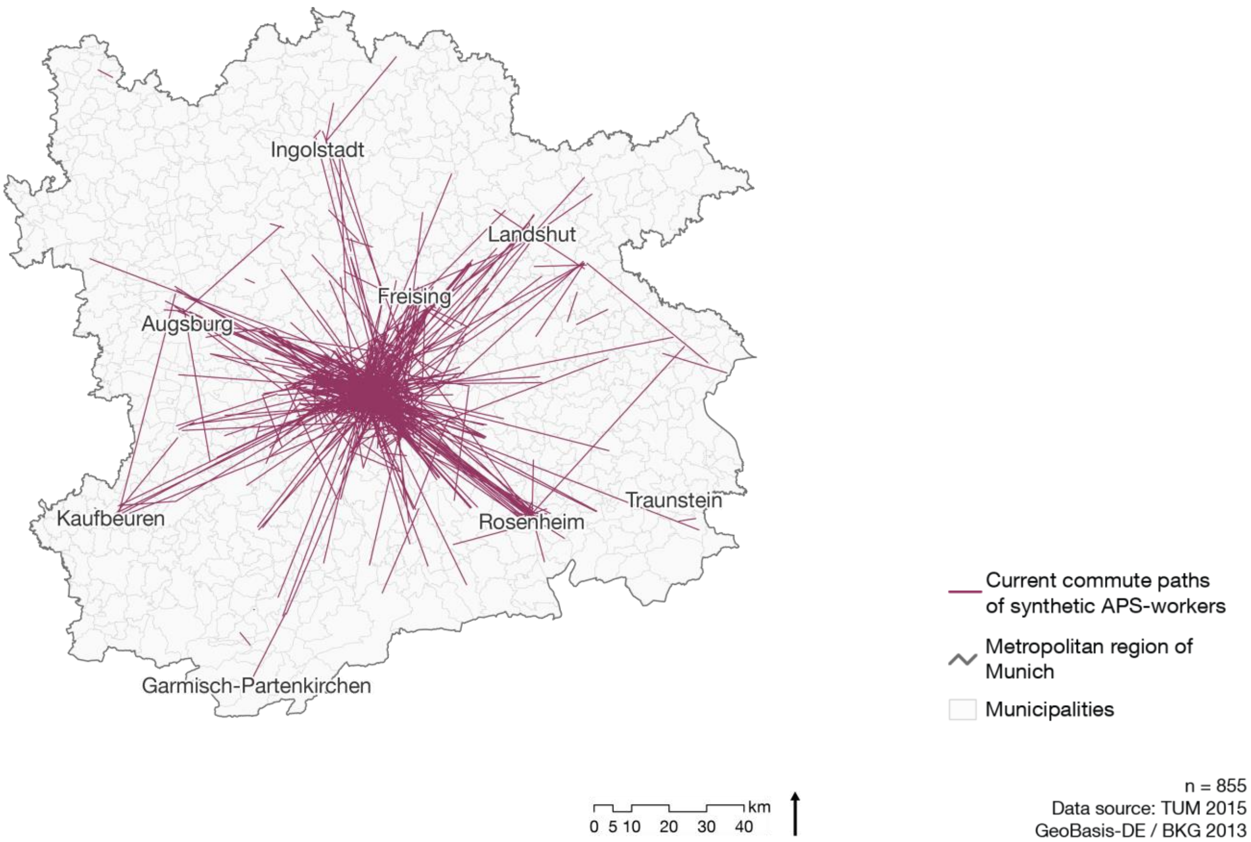


Figure 18. Current commute paths of synthetic APS-workers in MMR.

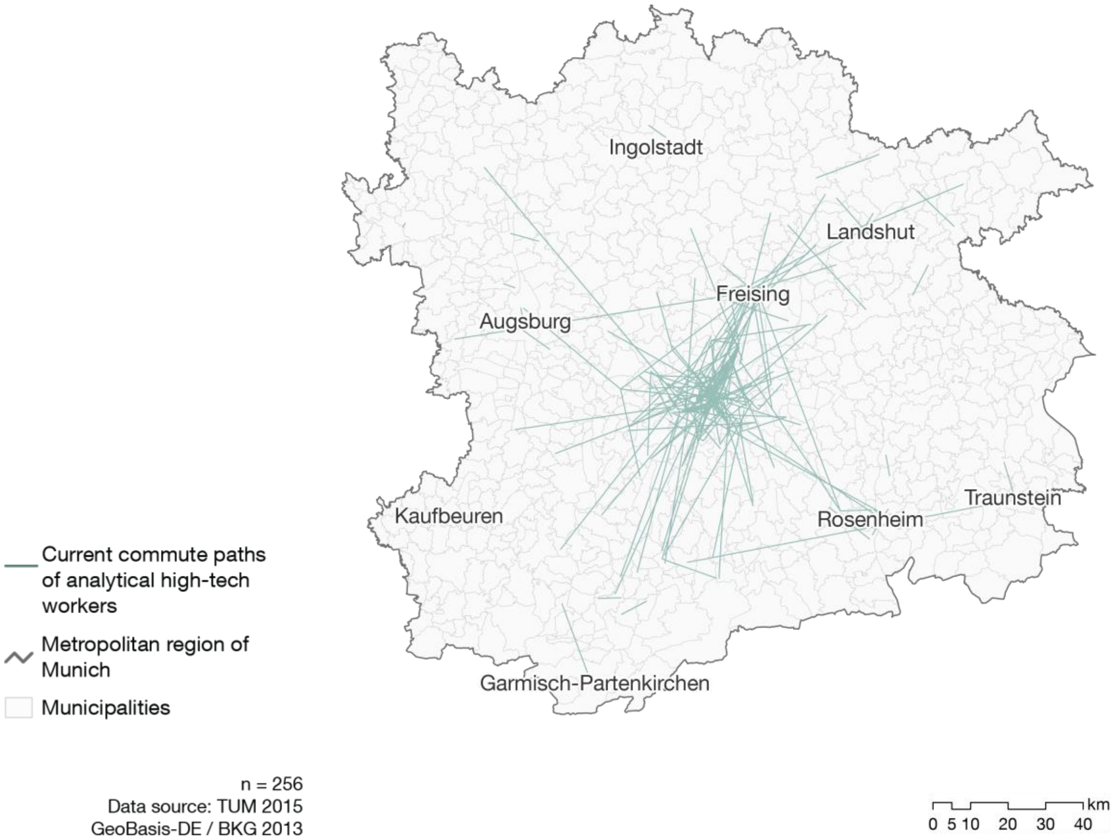


Figure 19. Current commute paths of analytical high-tech workers in MMR.

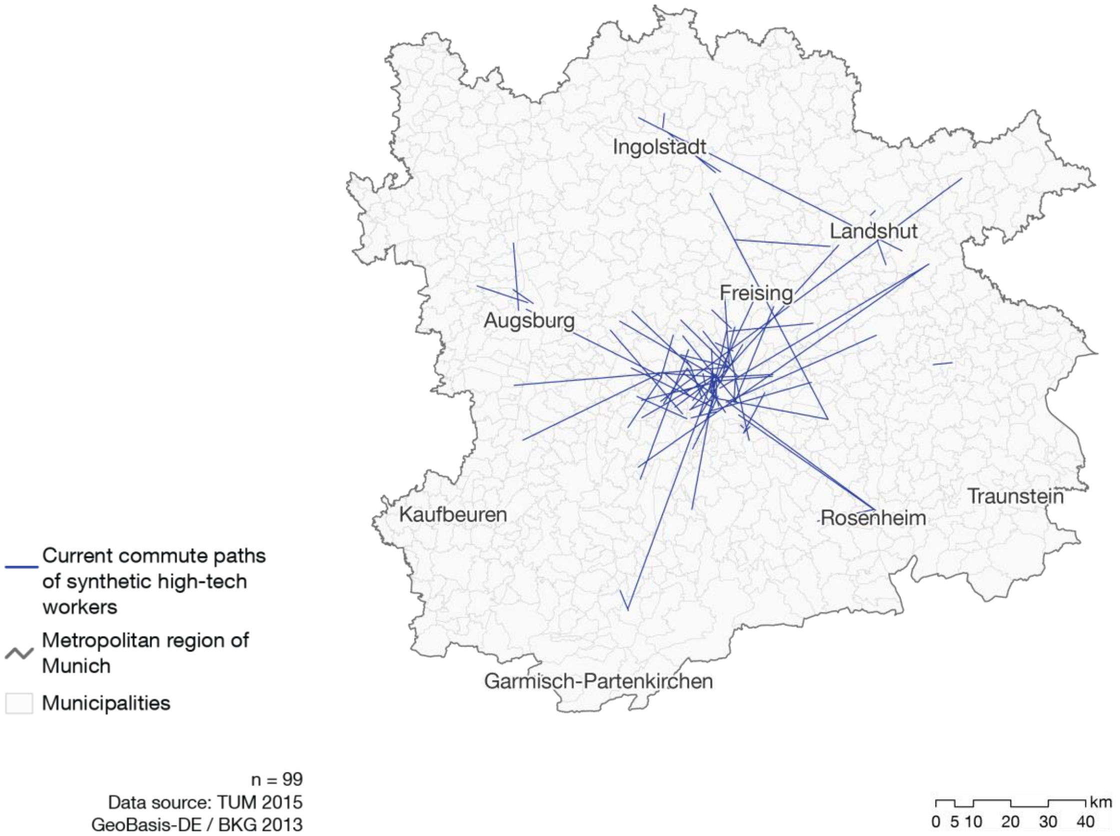


Figure 20. Current commute paths of synthetic high-tech workers in MMR.

Comparing the commute paths among each group of knowledge workers

Regarding the heavy overlapping of commute paths among both other workers and synthetic APS-workers, the description of commute paths focuses mainly on symbolic APS-workers, synthetic and analytical high-tech workers (Figures 16-20). Commute paths of symbolic APS-workers are closely related to the city of Munich: either completely contained within the city of Munich, or at least start or end with the city of Munich or its neighboring municipalities. In contrast, the commuting paths among synthetic high-tech workers are relatively less closely connected to the city of Munich, and 15% of commute paths even bypass the city of Munich, meaning both workplace and residence are located outside of the city of Munich. The relation between commute paths and the city of Munich among analytical high-tech workers differs from symbolic APS-workers, but is similar to synthetic high-tech workers. Different functional networks represented by commute paths among different types of knowledge workers underlie the housing and labor market within the metropolitan region of Munich. This region is most functionally monocentric when approached from the viewpoint of symbolic APS-workers' commute paths, and more functionally polycentric based on commute paths among synthetic high-tech workers.

6.1.2 Aggregated commute patterns with respect to central or non-central areas

The heavy overlapping of individual commute paths shown in the previous section suggests the necessity of aggregating them into an organized simpler pattern. With reference to the binary spatial-functional division between central and non-central areas, individual commute paths are categorized into four types. Commute within central areas (both residence and workplace in central areas); Commute to central areas (residence outside of central areas, workplace in central areas); Commute to non-central areas (residence in central areas, workplace outside of central areas); and commute within non-central areas (both residence and workplace outside of central areas). The following results are firstly based on comparing the distribution of four types of commute patterns among each group of workers, and, secondly, based on comparing the shares of subgroups of knowledge workers among each type of commute patterns.

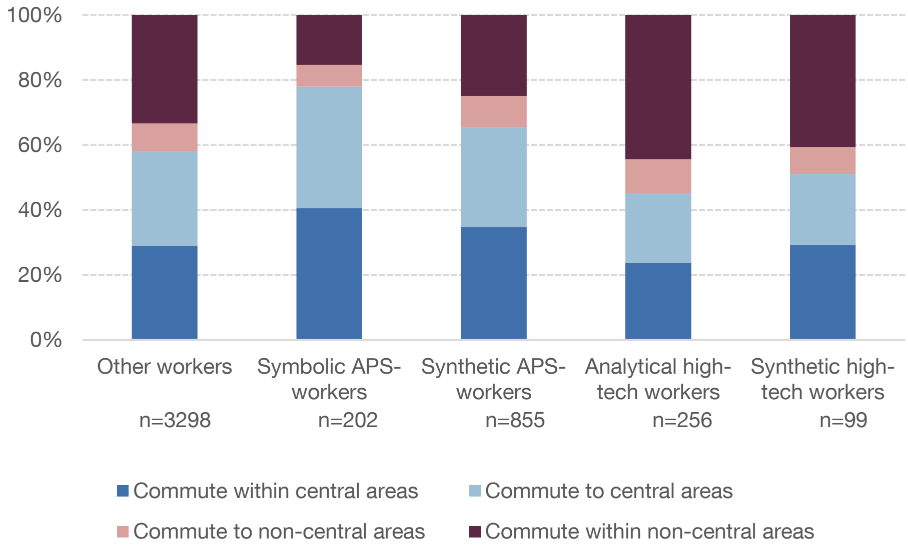


Figure 21. Current commute patterns (in relation to central or non-central areas) among each group of workers.

Firstly, the current distribution of four types of commute patterns among each group of knowledge workers is compared (Figure 21). Almost 80% (the share of commute within central areas plus the share of commute to central areas) of symbolic APS-workers' current workplaces are within central areas, which is the largest share among all groups of workers. 40% of symbolic APS-workers with both spatial anchor points (residence and workplace) are located in central areas. In contrast, only half of synthetic high-tech workers work within central areas, and 30% of them both work and reside in central areas. Synthetic APS-workers behave in a similar way to symbolic APS-workers but to a lesser extent, whereas analytical high-tech workers are more similar to synthetic high-tech workers.

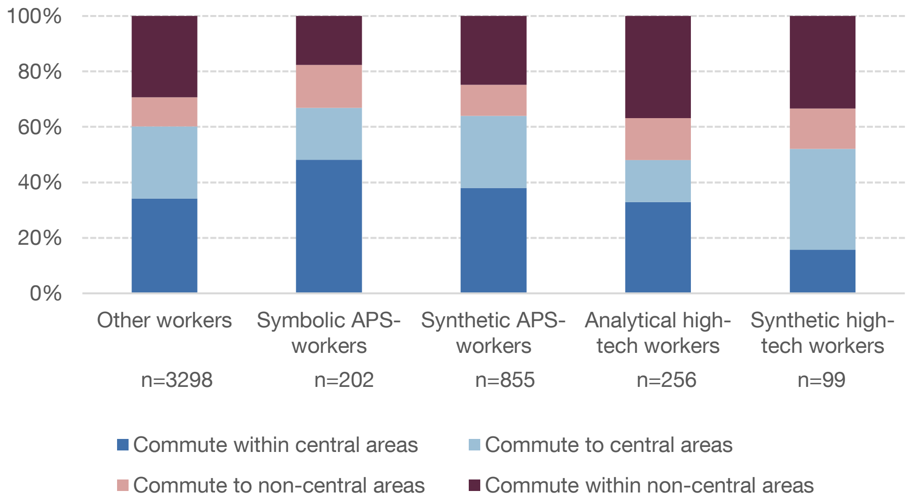


Figure 22. Previous commute patterns (in relation to central or non-central areas) among each group of workers.

If the current commute pattern is compared to previous commute pattern (Figure 22), it is revealed that the share of central workplaces among symbolic APS-workers increased from 70% to 80% and the share of commuting to non-central areas decreased correspondingly from 15.5% to 6.7%. Although there is no apparent change of the spatial distribution of workplaces among synthetic high-tech workers, the share of synthetic high-tech workers who both live and work in central areas increased from 15.4% to 29.2%, which results from approximately 14% of them moving residential locations from non-central areas to central areas. This contradicts the hypothesis that synthetic high-tech workers tend to deconcentrate in space.

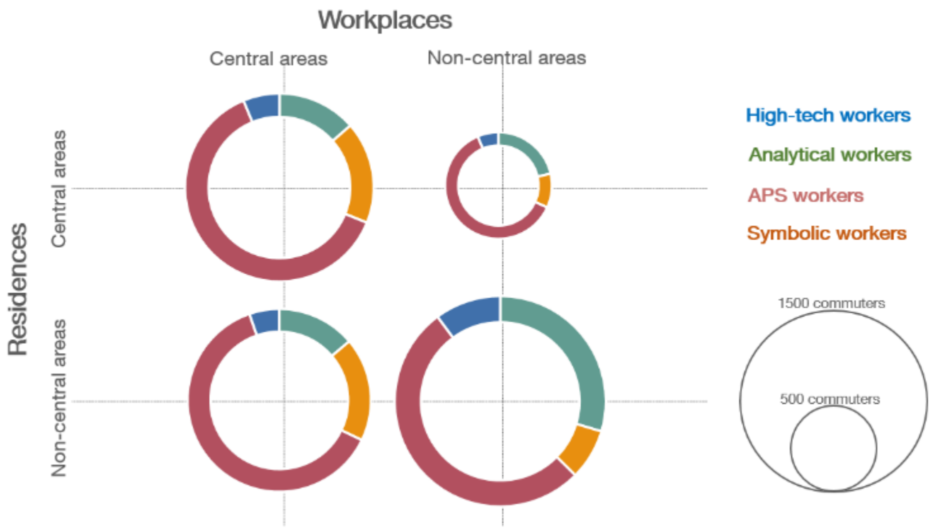


Figure 23. Shares of subgroups of knowledge workers within each type of commute patterns in relation to central or non-central areas.

Secondly, comparing the commute patterns can also be approached by examining the shares of each group of workers within each type of commute pattern (Figure 23). Regarding the disproportionally large share (71%) of other workers within the total sample, the diagram of commute pattern includes only four subgroups of knowledge workers to present more clearly the differences among these subgroups. Similarly, it is noticed that the share of synthetic and analytical high-tech workers commuting among non-central areas is much larger than other types of commute pattern. In contrast, the share of symbolic and synthetic APS-workers commuting within or commute to central areas is much larger than other types of commute pattern.

When focusing on the total number of knowledge workers between these four patterns of commute, it is observed that the share of commute within central areas and commute to central areas among knowledge workers is larger than the commute between non-central areas and the commute to non-central areas. This is also as expected, since knowledge-intensive job opportunities are more concentrated in central areas compared to residences.

6.1.3 Distribution of commute length in distance categories

Alongside the spatial patterns of individual commute paths, the exact length as well as the mean length of the commute is calculated (Table 5). Extremely long commutes greater than 60km, amounting to 10% of total commute trips, are excluded. The average commute distance in the current situation is largest among synthetic high-tech workers, and decreases respectively from analytical high-tech workers, other workers and synthetic APS-workers to symbolic APS-workers. Before a residential move, it is also observed that the average commute distance among analytical and synthetic high-tech workers is longer than that of symbolic and synthetic APS-workers. The commute distances of other workers also lie in between these two groups of knowledge workers. The results above are consistent with the assumption that synthetic and symbolic APS-workers have a larger demand for job-housing proximity compared to workers in high-tech industries.

Table 5.The average length of the previous and current commute among each group of workers (Author's own calculation):

Commute length	Other workers (n=3298)	Symbolic APS-workers (n=202)	Synthetic APS-workers (n=855)	Analytical high-tech workers (n=256)	Synthetic high-tech workers (n=99)
Previous commute (km)	9.6	7.4	9.1	12.2	10.0
Current commute (km)	9.1	7.5	8.9	13.3	16.4

In addition, the commute distance is categorized into five categories: less than or equal to 5km, between 6km and 10km, between 11km and 15km, between 16km and 20km, and equal to or between 21km and 60km. It is revealed that the previous share of long commutes (21-60km) among synthetic high-tech workers is the largest, and least among symbolic APS-workers (Figure 24). In addition, the share of short commutes (less than 5km) among symbolic APS-workers is the largest, whereas the share is least among synthetic high-tech workers.

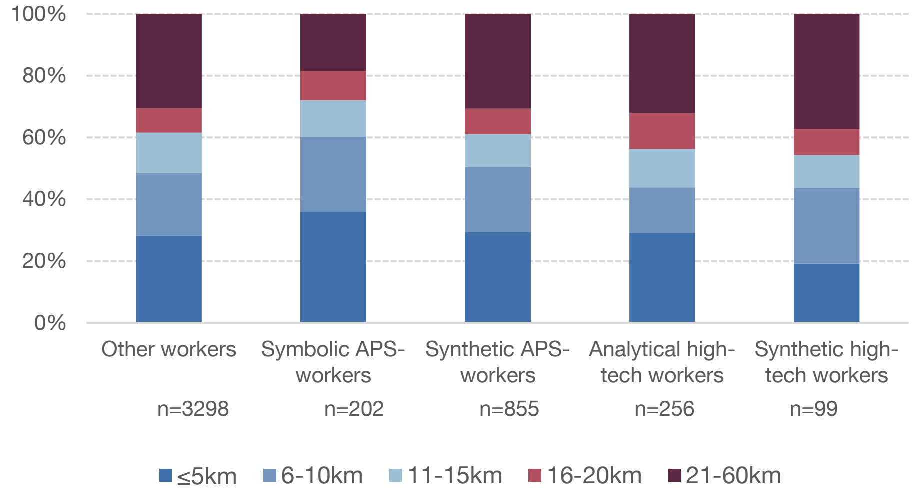


Figure 24. Distribution of commute lengths before the residential move.

Similar findings appear when focusing on the current situation (Figure 25). The share of long commutes (21-60km) among analytical high-tech workers amounts to 40%, which is as large as that among synthetic high-tech workers. This differs greatly from symbolic and synthetic APS-workers in the APS sectors (less than 30%). Regarding relatively short commutes (less than 10km), the share among symbolic APS-workers and synthetic APS-workers is apparently larger than that among analytical and synthetic high-tech workers. When focusing on the change of commute distance, it is noticed that among analytical and synthetic high-tech workers, the share of relatively long commutes (larger than 16km) increases after a residential or job change, which is accompanied by a decrease in the share of relatively short commute distances (between 6km and 10km).

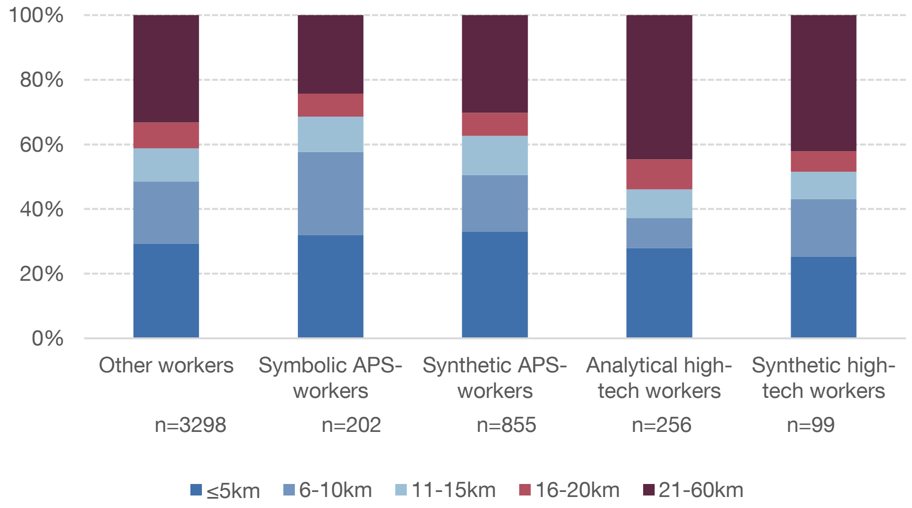


Figure 25. Distribution of commute lengths after the residential move.

6.1.4 Distribution of residences and workplaces with respect to Munich

Each individual is positioned in the coordinate system based on the respective distance (measured in kilometers) between individuals' workplace and residence location and the city center of Munich (Figures 26-31). The residences and workplaces of symbolic APS-workers are mostly concentrated closer to the city center of Munich, whereas both synthetic high-tech workers' residence and workplace locations are distributed further from the city center. Among analytical high-tech workers and synthetic APS-workers, the range of the distances between workplaces and the city of Munich is smaller compared to their residences. This is in accordance with existing settlement structure: a relatively higher concentration of the land use for production compared to the land assigned to residential usage. Other workers are more concentrated compared to synthetic high-tech workers. Nevertheless, their lower willingness to pay for central, highly accessible locations result in larger distances of their residences to the city of Munich than symbolic APS-workers.

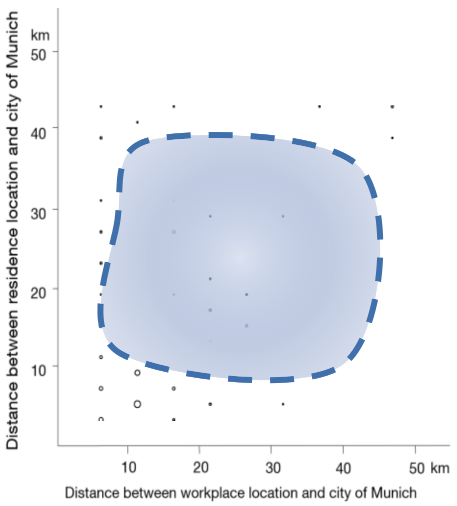


Figure 26. Distance of residence and workplace to the city of Munich among high-tech workers (n=99).

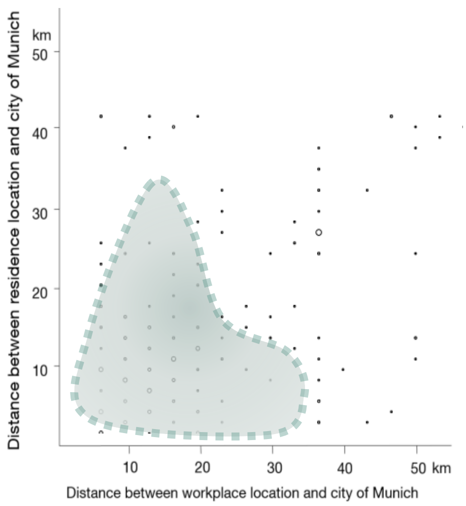


Figure 27. Distance of residence and workplace to the city of Munich among analytical workers (n=256).

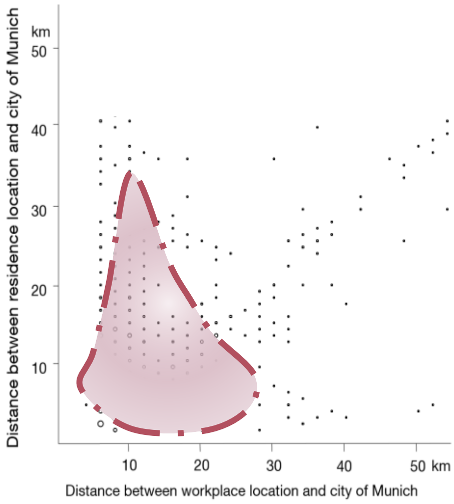


Figure 28. Distance of residence and workplace to the city of Munich among APS workers (n=855).

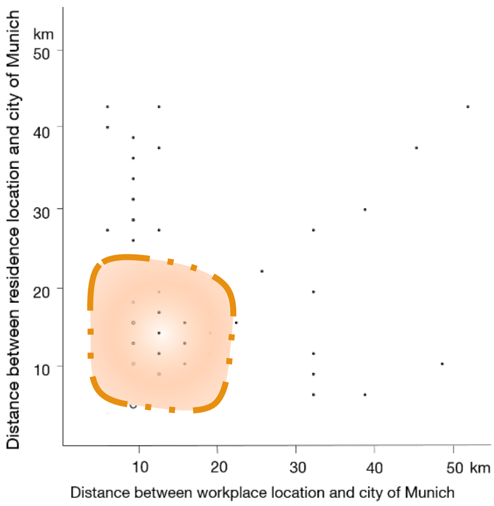


Figure 29. Distance of residence and workplace to the city of Munich among symbolic workers (n=202).

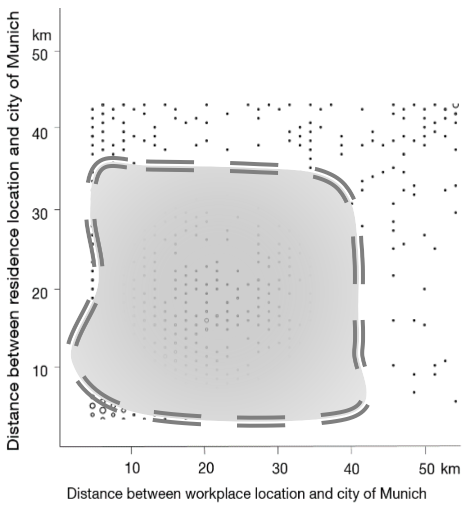


Figure 30. Distance of residence and workplace to the city of Munich among other workers (n=3298).

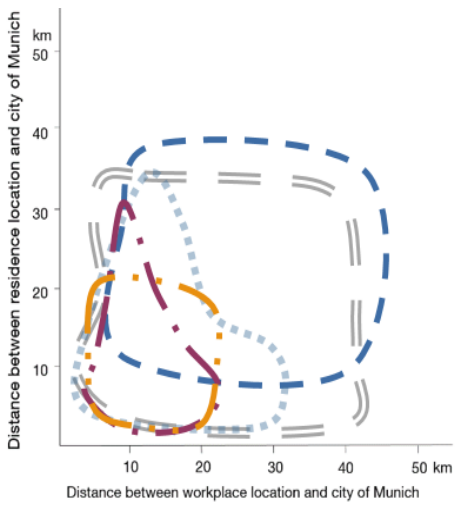


Figure 31. Distance of residence and workplace to the city of Munich among each group.

Centroid of residence and workplace locations: 'abstract' commute path

In addition, the concept of centroid is applied to further aggregate individual-based commute trips (section 6.1.1). The centroids (mean X and Y coordinates) of all current residence and workplace locations among each group of workers are calculated. This to some extent represents the overall distribution and orientation of residences and workplaces in the region. To better facilitate the spatial orientation, 'Marienplatz', as a proxy for the city center in Munich, is used as the spatial reference point. Since the centroids are either located within or being neighboring to the city of Munich, the spatial extent of display is zoomed in to the city of Munich to better present their differences (Figure

32). There is a clear division between the group of symbolic and synthetic APS-workers (workers in APS sectors), and the group of analytical and synthetic high-tech workers (workers in high-tech industries). Symbolic and synthetic APS-workers are generally more city-center oriented, since the city center of Munich functions as an important pole or hub of knowledge exchanges in the region. Both the centroids of their workplaces and residences are far from the city center among synthetic high-tech workers. In addition, the centroid of workplaces is even further from the center, that is, the overall distribution of workplaces is even more low-density oriented compared to residences. This corresponds to the location strategy of high-tech industries in that these industries locate in relatively peripheral locations for the sake of the specialization and sharing of relevant supporting facilities. The centroids of other workers' residences and workplaces are located between workers in high-tech and workers in APS sectors.

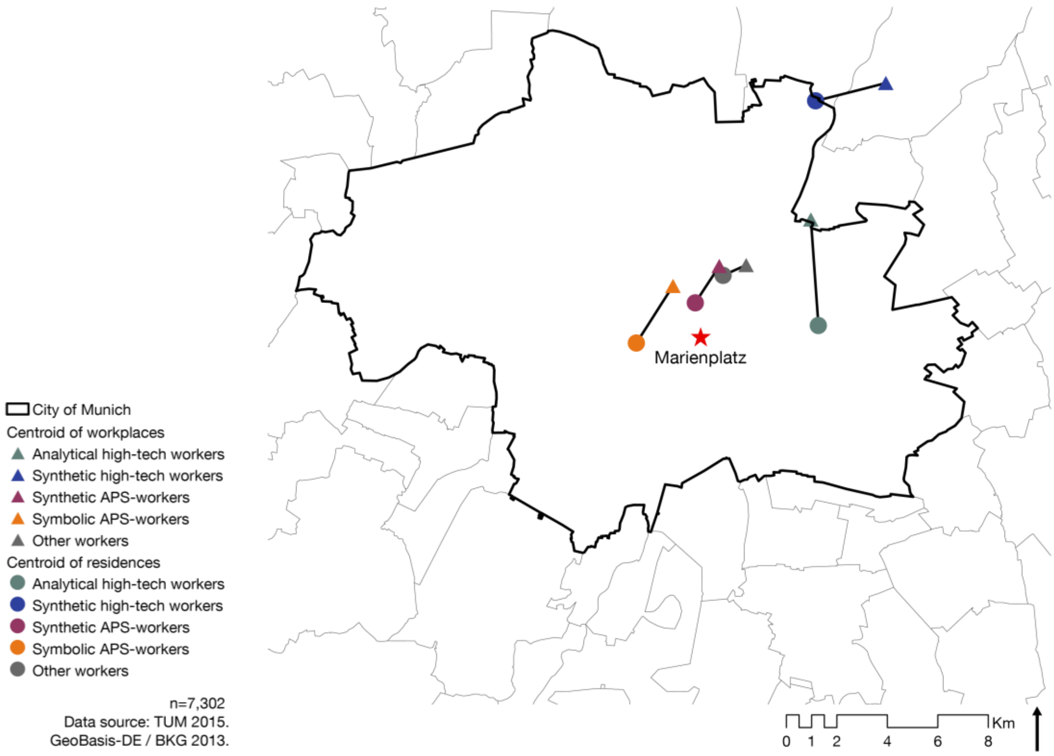


Figure 32. Centroids of residence and workplace locations among each group of workers.

6.1.5 Change of spatial proximity between residence and workplace

As commute depends on both the location of residence and workplace, the response of individual commute distance on a joint change of residence and workplace reflects attitude towards the housing-job proximity. Here individuals who changed both housing and job at the same time are analyzed. As shown in Figure 33, all synthetic high-tech workers increase their commute lengths. In contrast, more than 80% of other groups of knowledge workers shorten the commute distance after the joint change of residence and workplace location. Other workers show a slightly larger tendency to shorten the commute distance as opposed to than lengthening it.

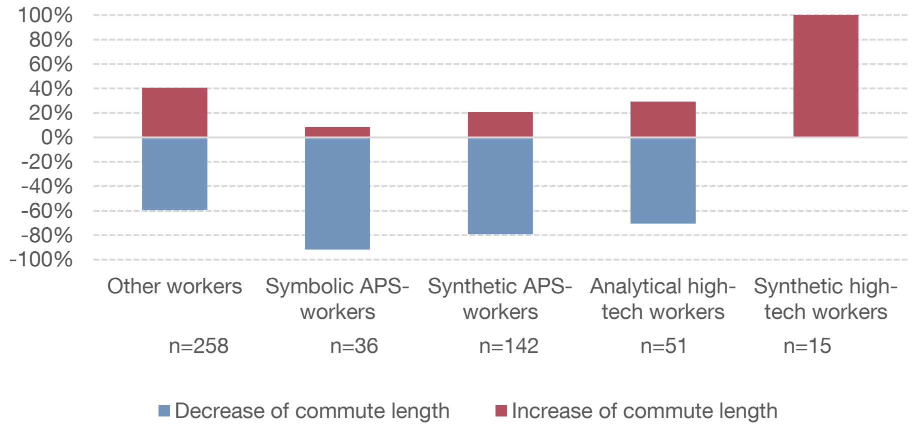


Figure 33. Change of the commute length after residential move and job change.

6.2 (De-)Concentration process in space

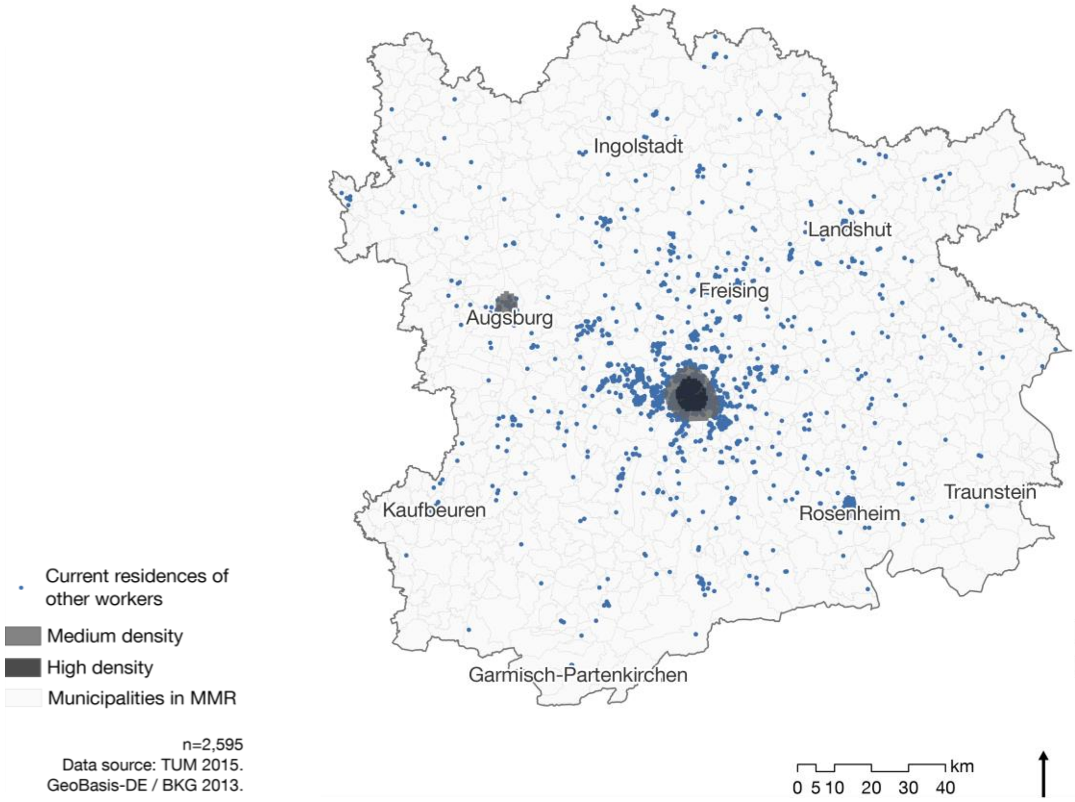
This section will firstly compare the previous and current distribution of residential locations across different groups of workers. Secondly, it investigates the underlying unobservable spatial processes, namely the invisible movement from the alternative residence to current residence. Lastly, since the update from a rented residence to purchased residence is closely associated with the de-concentration process, the comparison between housing ownership previously and currently is also conducted.

6.2.1 Spatial distribution of previous and current residences

The analysis focuses on individuals that have moved residences within the metropolitan region, regardless of whether job location is changed or not.

6.2.1.1 Kernel density of previous and current residence locations

Kernel density is applied to better grasp the overall spatial distribution of residences. Four classifications of kernel density using the natural interval method are selected. To better depict the areas of concentration, the first and second level (relatively lower value) of density are not displayed in the spatial clusters of the residences, the third and the highest level (relatively higher value) of density are displayed and labeled respectively as medium-density and high-density residential areas. In addition, exact individual geographic locations of residences are also included in the map to facilitate interpretation.



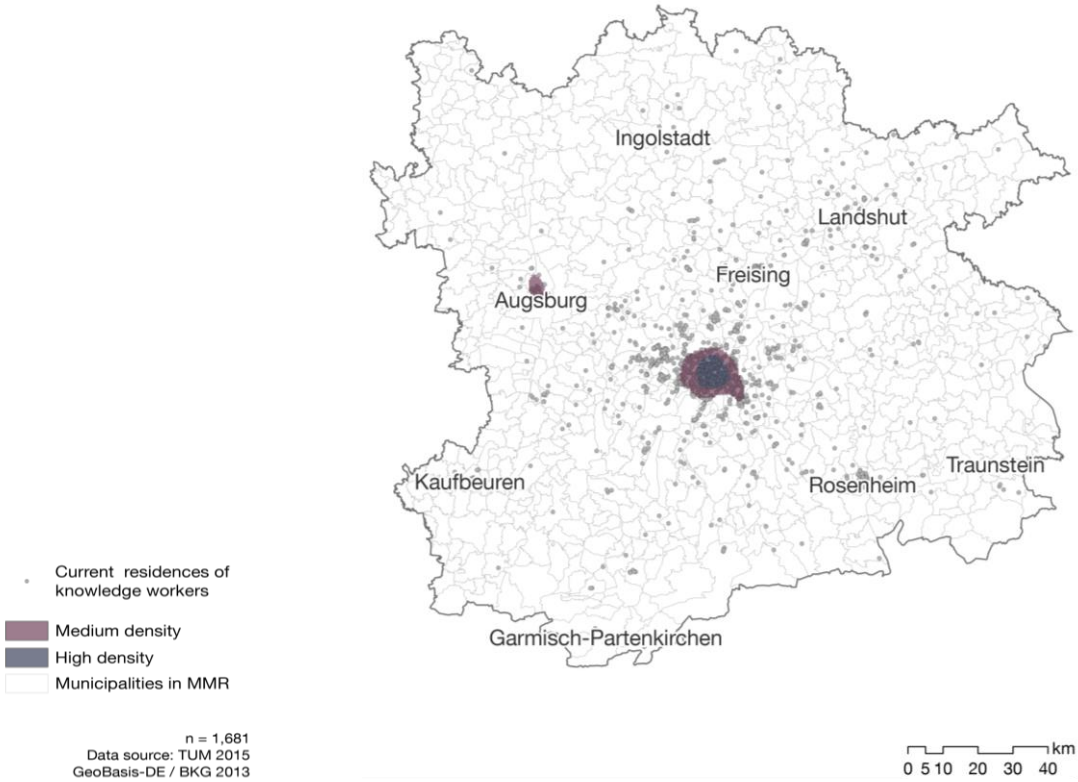


Figure 34.Kernel density of current residences among other workers (above) and knowledge workers (below)

As shown in Figure 34, the spatial distribution of the concentrated residential areas among knowledge workers does not differentiate much from that of other workers. Both knowledge workers and other workers concentrate mainly in the city of Munich and the city of Augsburg.

Comparison of knowledge workers and other workers

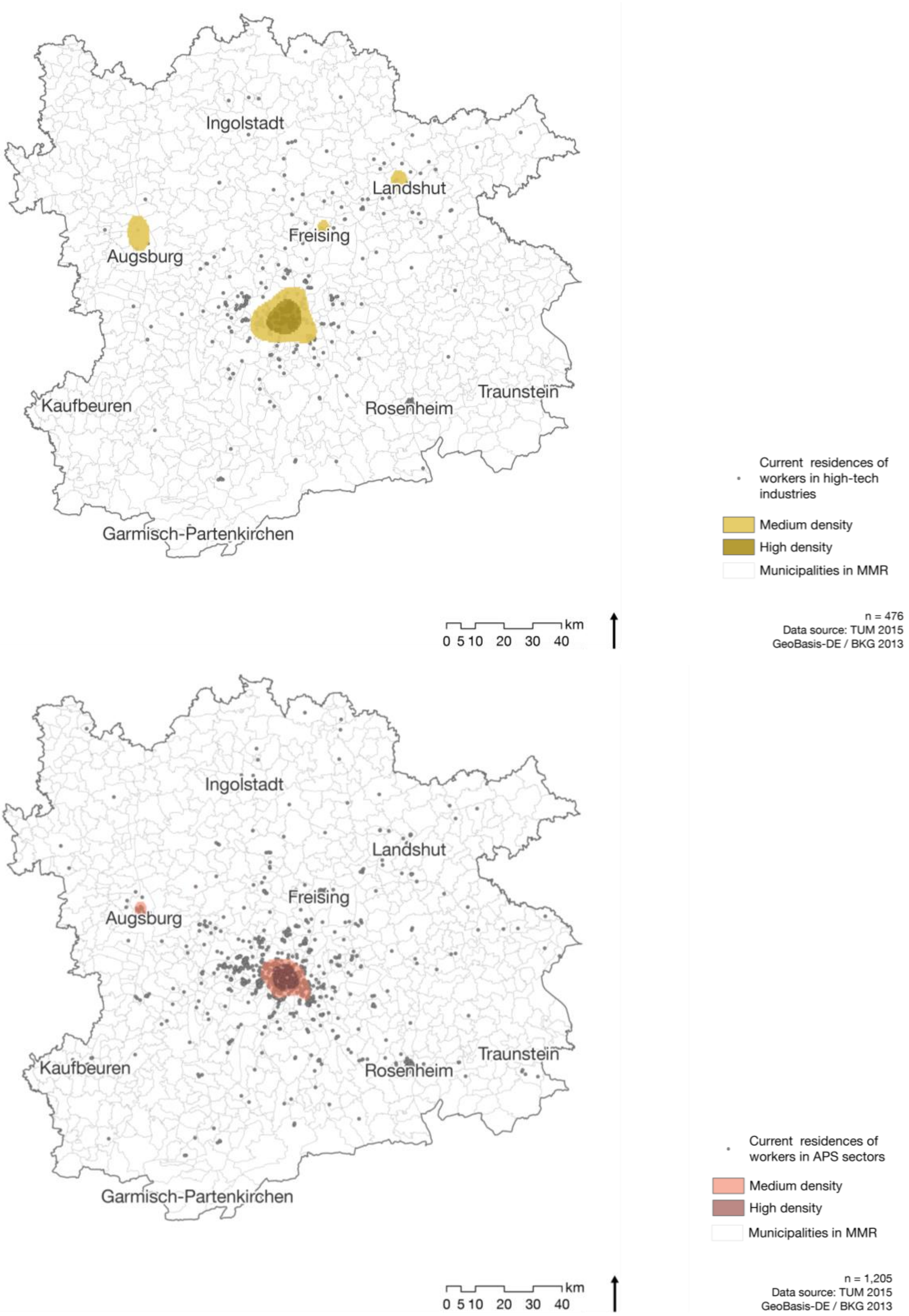


Figure 35.Kernel density of current residences among workers in high-tech industries (above) and workers in APS sectors (below) .

Comparison of workers in high-tech industries and APS sectors

When focusing on the comparison between workers in each sector, it is revealed that the degree of concentration of synthetic high-tech workers' residences is less than that of synthetic APS-workers (Figure 35). The areas with high density among synthetic high-tech workers is larger than that among synthetic APS-workers. In addition, the concentrated space is no longer limited to Munich and Augsburg, but also extended to Landshut and Freising. This supports the first hypothesis.

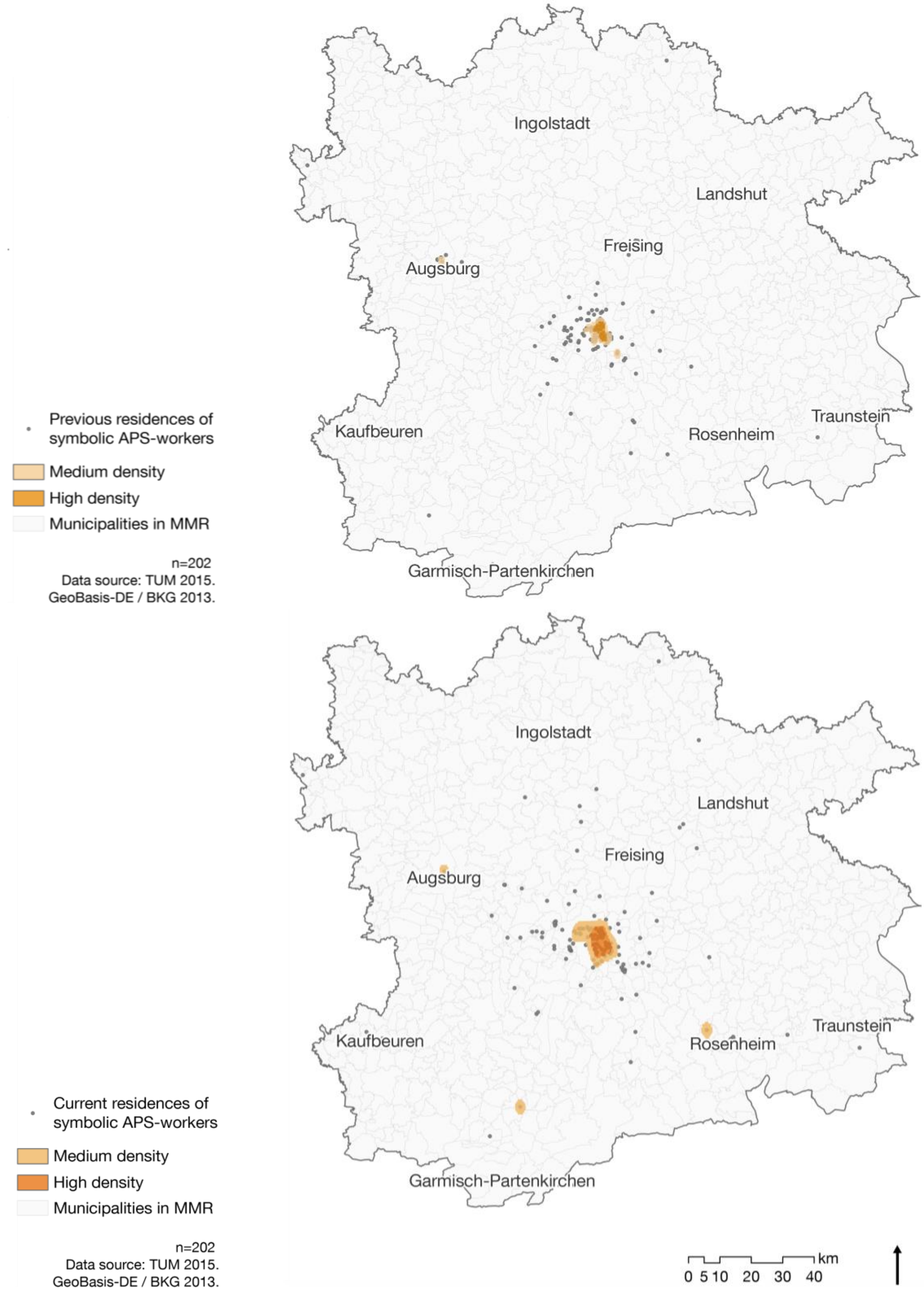


Figure 36. Kernel density of previous (above) and current (below) residences of symbolic APS-workers.

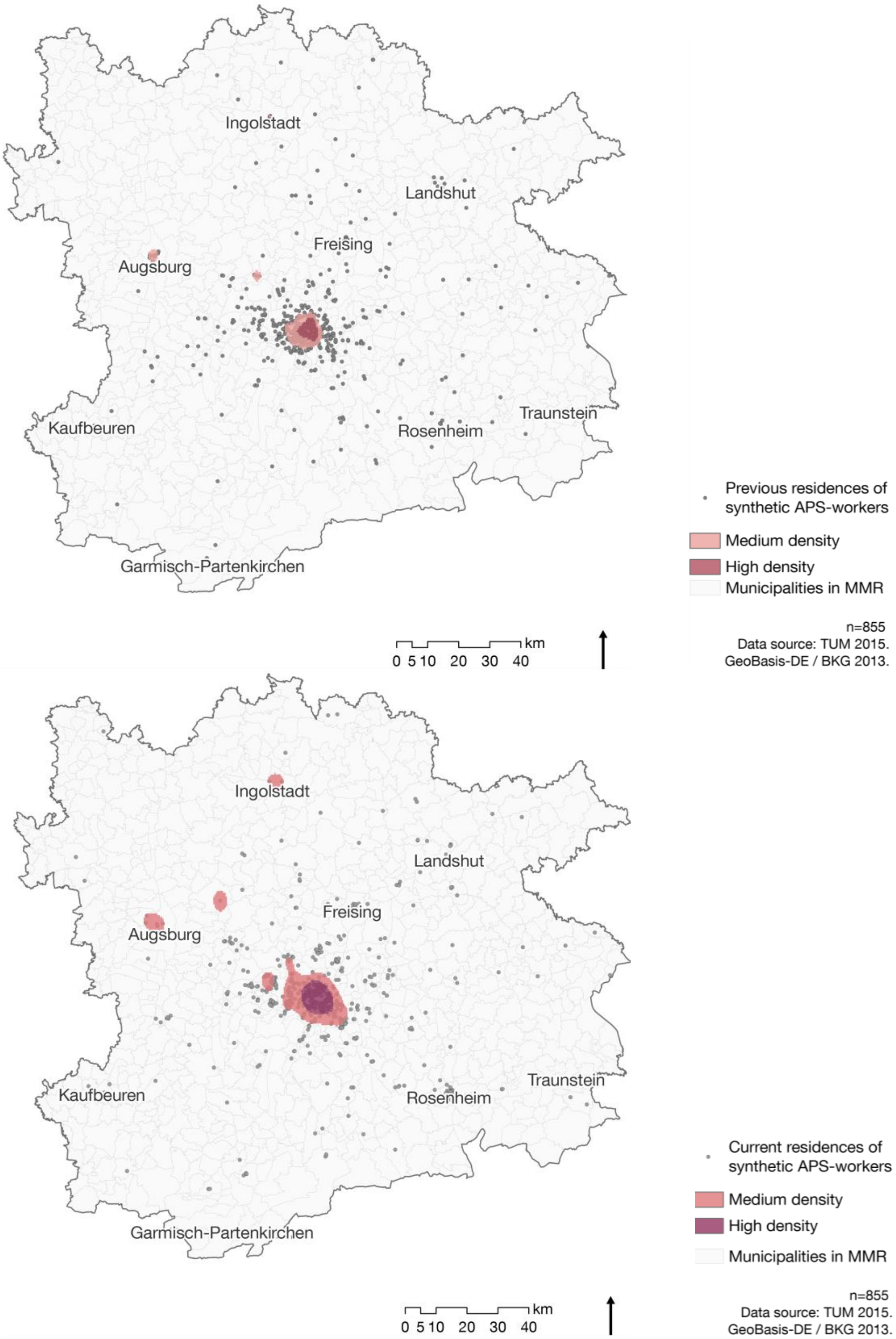
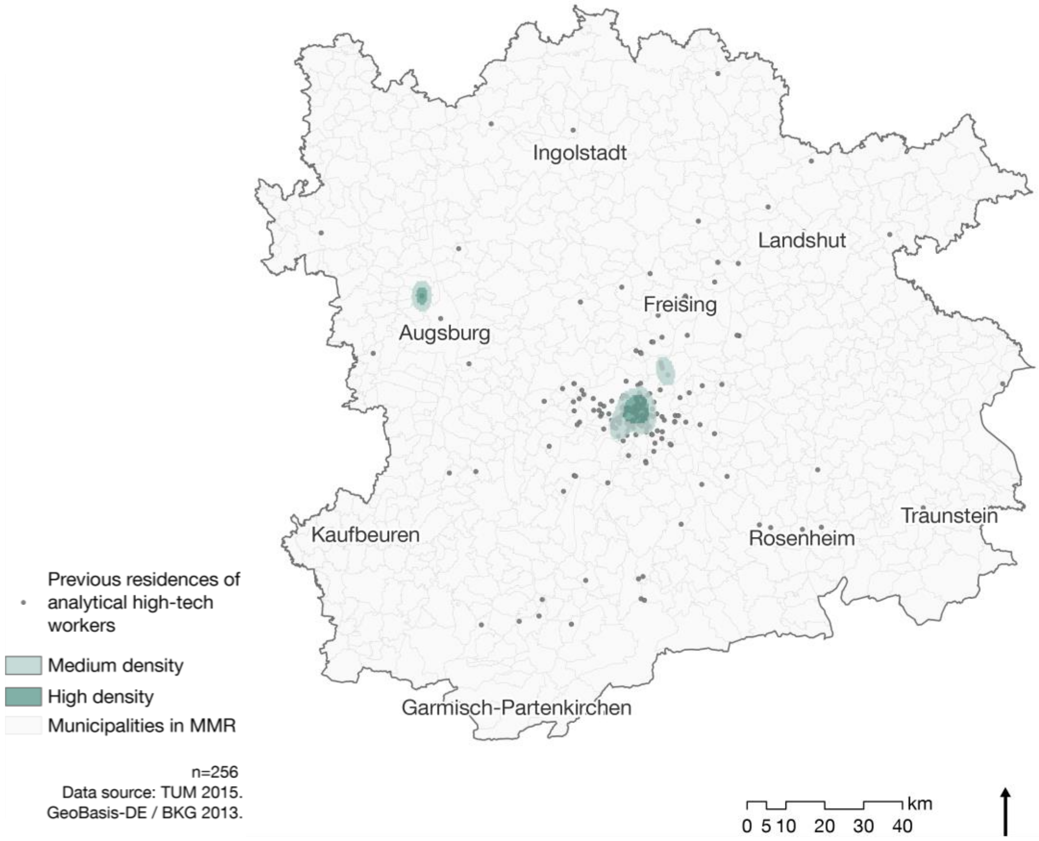


Figure 37. Kernel density of previous (above) and current (below) residences of synthetic APS- workers.



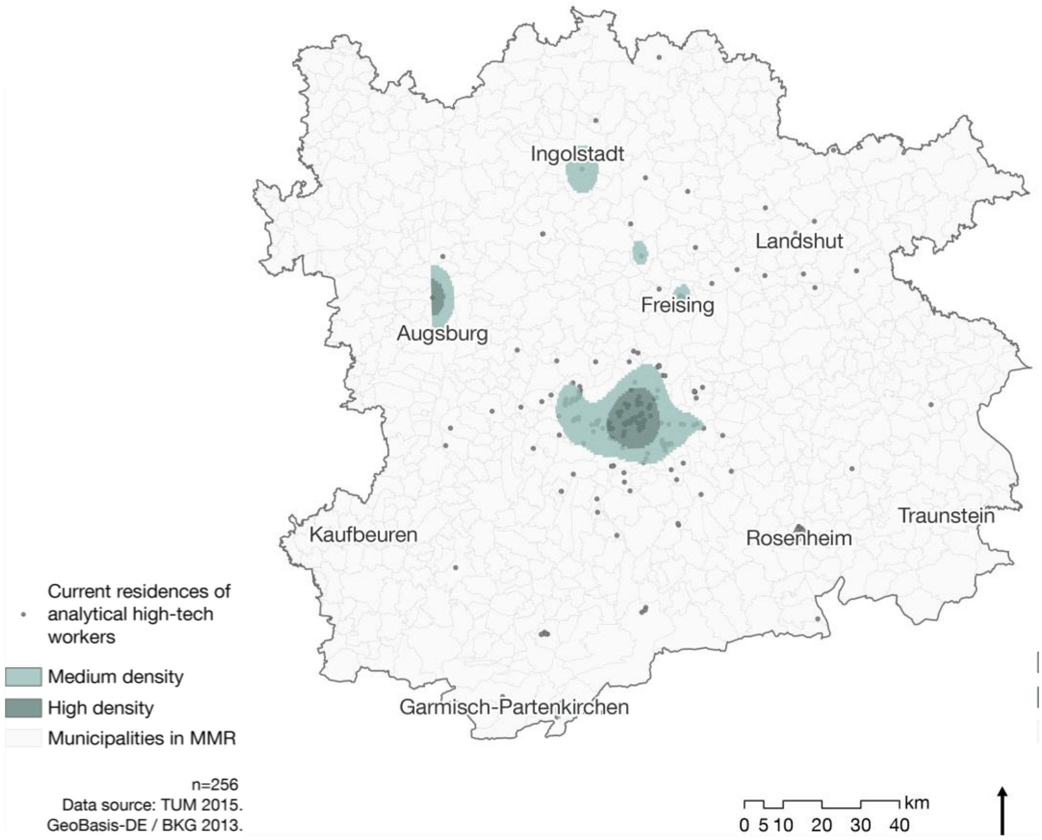
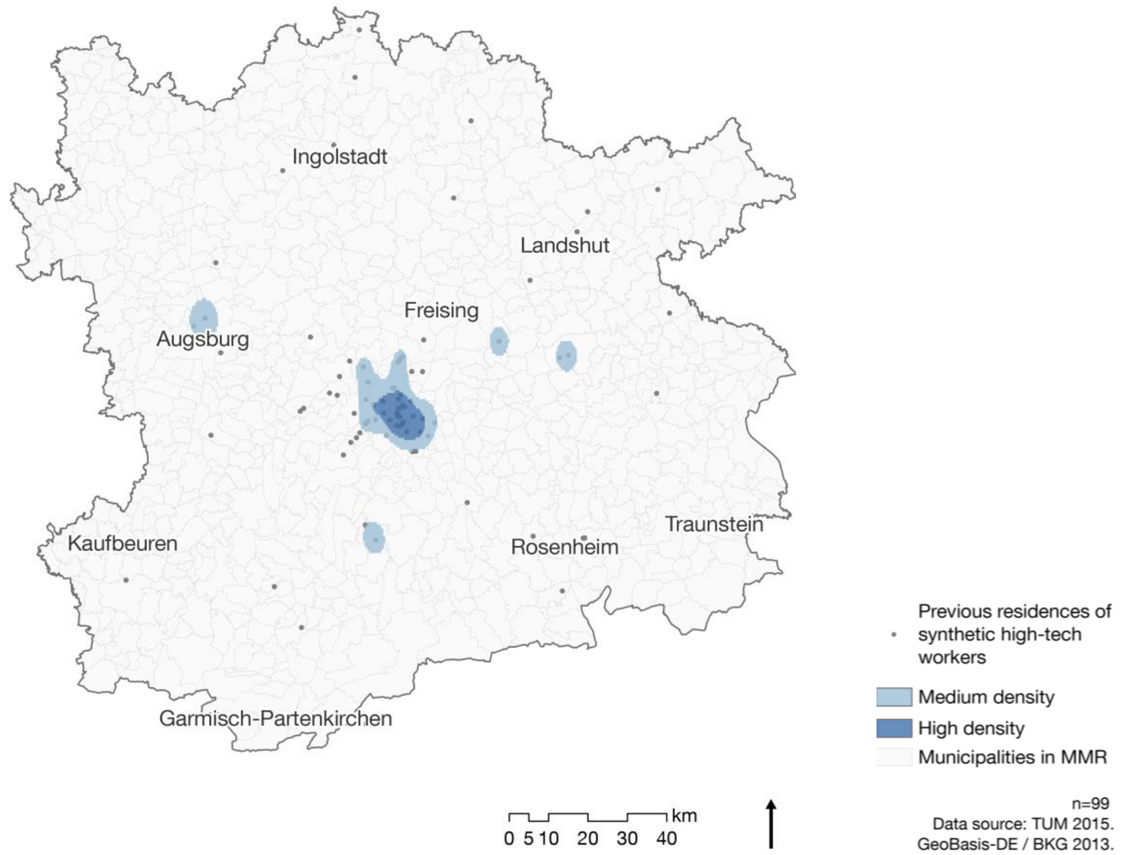


Figure 38. Kernel density of previous (above) and current (below) residences of analytical high-tech workers.



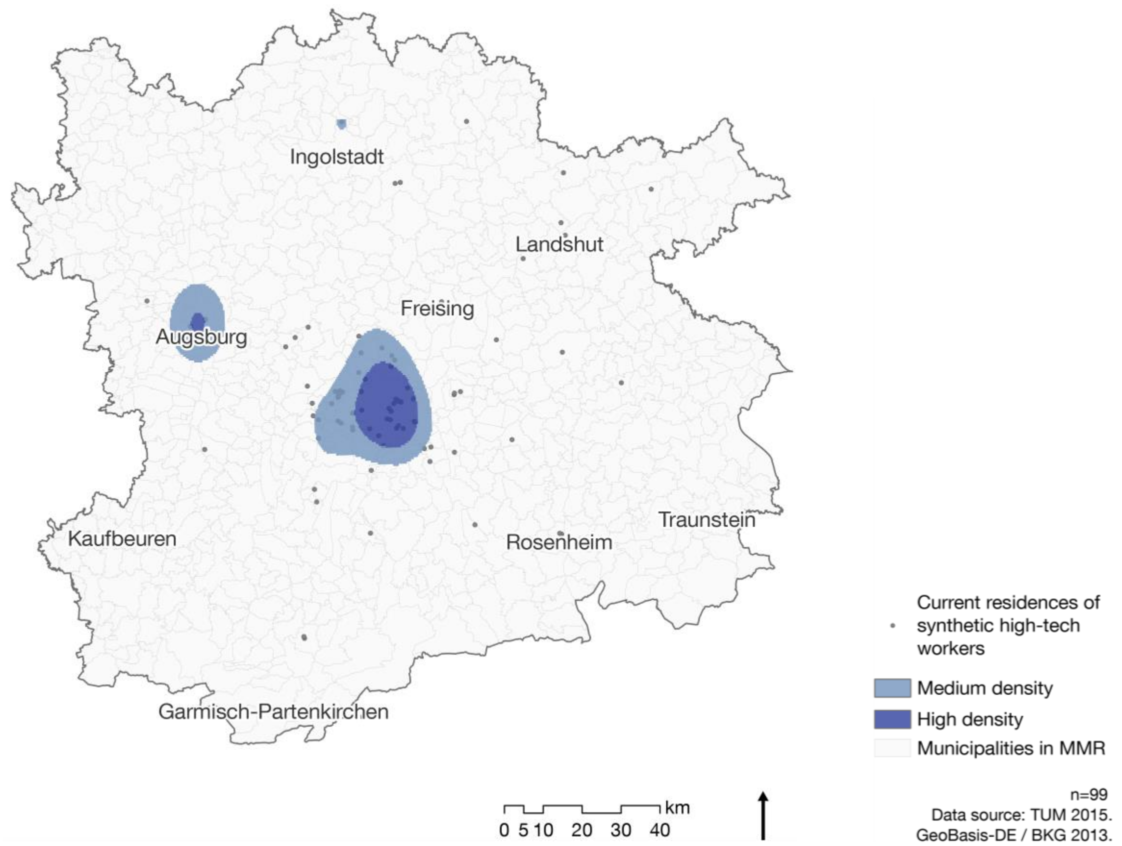


Figure 39. Kernel density of previous (above) and current (below) residences of synthetic high-tech workers.

Comparison of synthetic high-tech workers, analytical high-tech workers, synthetic APS-workers, and symbolic APS-workers

The kernel density of residences among each subgroup of knowledge workers is now presented in Figures 36-39. By comparing the spatial maps between previous and current situation, the enlargement of the spatial extent of areas with higher density shows a general pattern of de-concentration among all groups of workers. However, the de-concentration is varies by degree among each type of knowledge workers. Before moving residence, all groups of workers disproportionally concentrate in the city of Munich. In terms of the current situation, the concentration of synthetic and analytical high-tech workers is no longer limited to the city of Munich; the neighboring municipalities also host a large number of these knowledge workers. The current spatial distribution of concentrated residential areas among symbolic APS-workers (after the residential move/dispersion) is similar to the current pattern of synthetic high-tech workers (before the residential move/dispersion). To summarize, analytical and synthetic high-tech workers show a more apparent de-concentration than symbolic and synthetic APS-workers.

In addition, the difference among groups of workers also based on a cross-sectional comparison is also apparent (Figures 36-39). By comparing the spatial extent of areas with higher kernel density in the current situation, it is revealed that the distribution of residences of symbolic APS-workers shows the highest degree of concentration, whereas synthetic high-tech workers demonstrate the most dispersed pattern. The distribution pattern of analytical high-tech workers' residence locations is similar to that of synthetic high-tech workers and the distribution pattern of synthetic APS-workers' residences is similar to that of symbolic APS-workers.

6.2.1.2 Hotspots of residence locations

Apart from kernel density analysis, hotspot analysis is further applied both to the metropolitan region and to the city of Munich, since it also verifies whether the cluster or concentration is statistically significant or not (whereas kernel density does not). Hotspots will be identified if there is a high concentration of knowledge workers within a given spatial unit as well as its neighboring spatial units (The search radius is set as 4km for the whole region). In contrast, cold spots will be identified if there is a low concentration within the spatial unit as well as its neighboring areas. One of the key advancements of this measurement is the consideration of the neighboring area, thus directly connected to the likelihood of running into like-minded people within the areas in the vicinity.

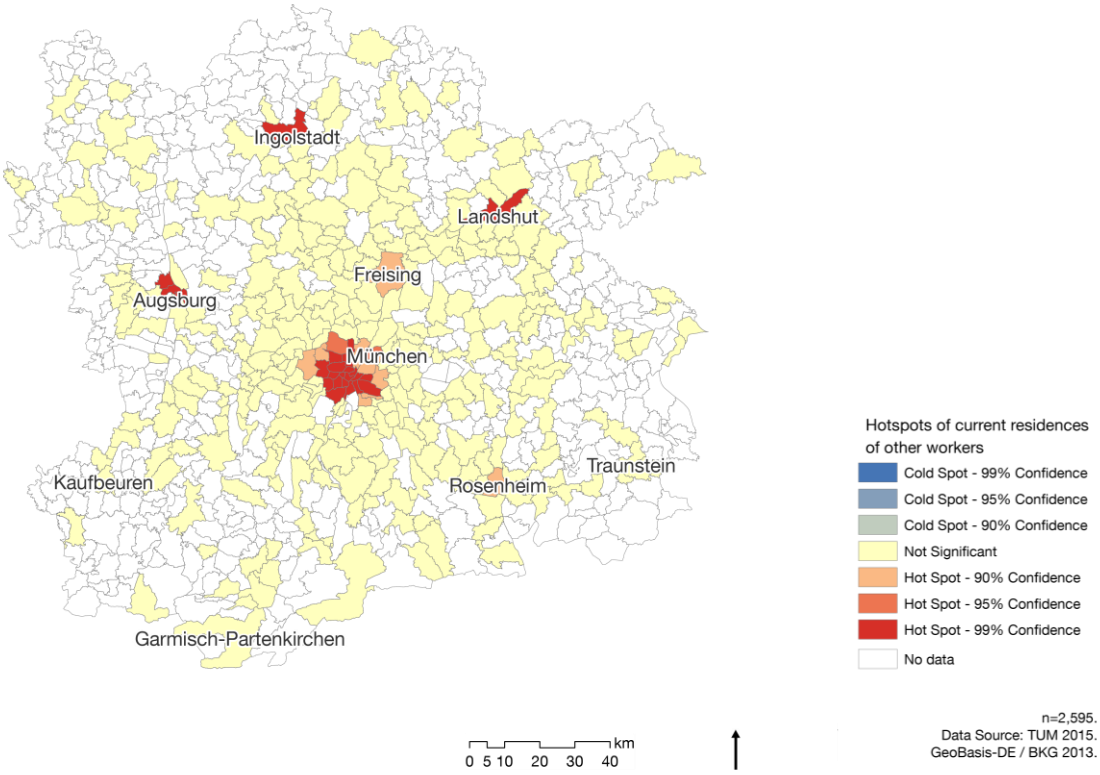


Figure 40. Distribution of residences among other workers in the MMR.

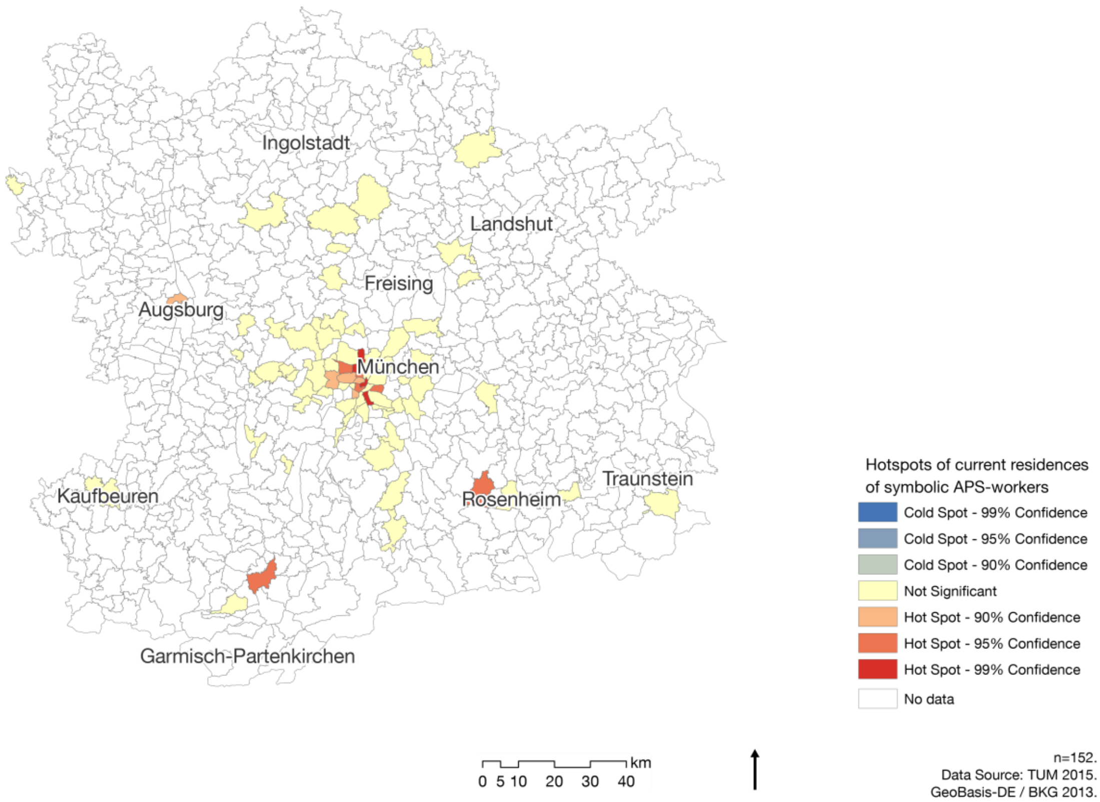


Figure 41. Distribution of residences among symbolic APS-workers in the MMR.

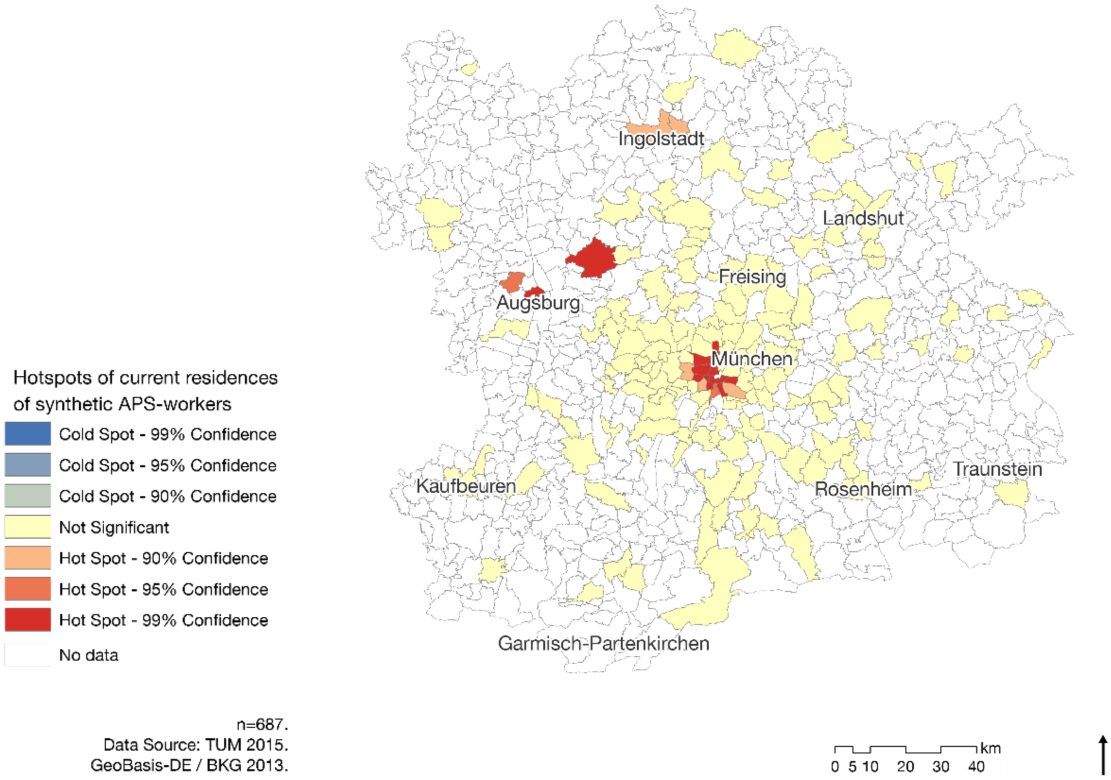


Figure 42.Distribution of residences among synthetic APS-workers in the MMR.

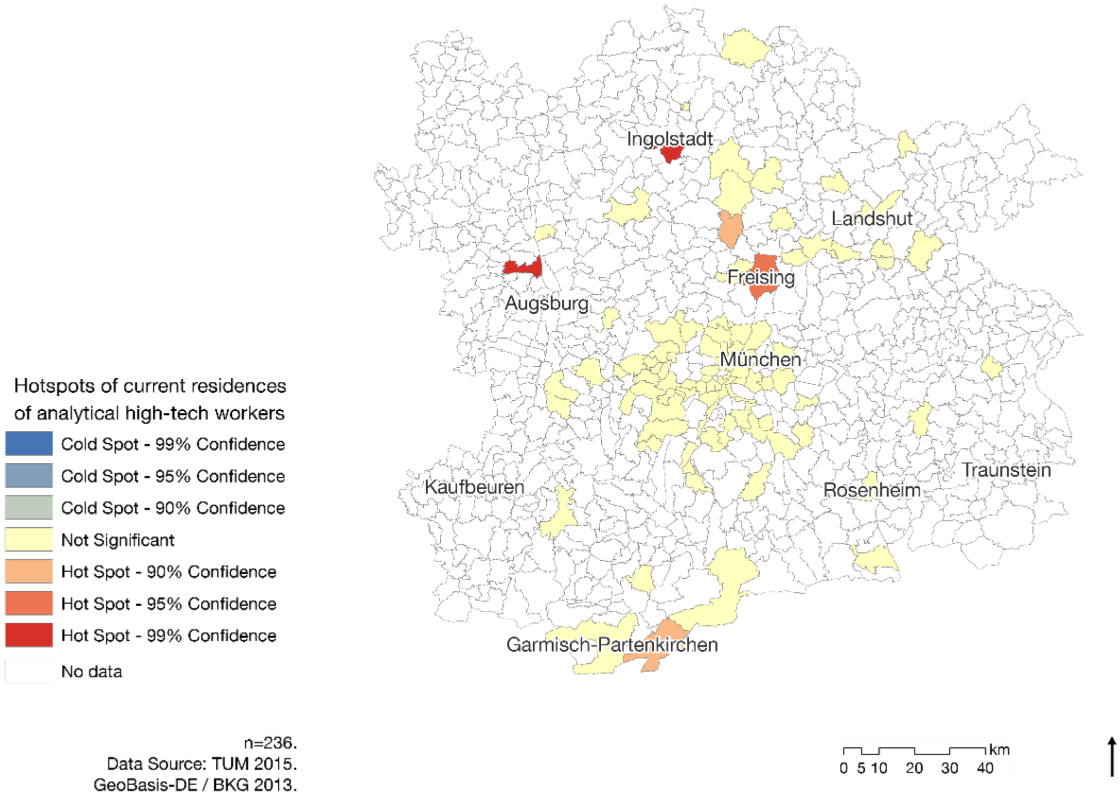


Figure 43. Distribution of residences among analytical high-tech workers in the MMR.

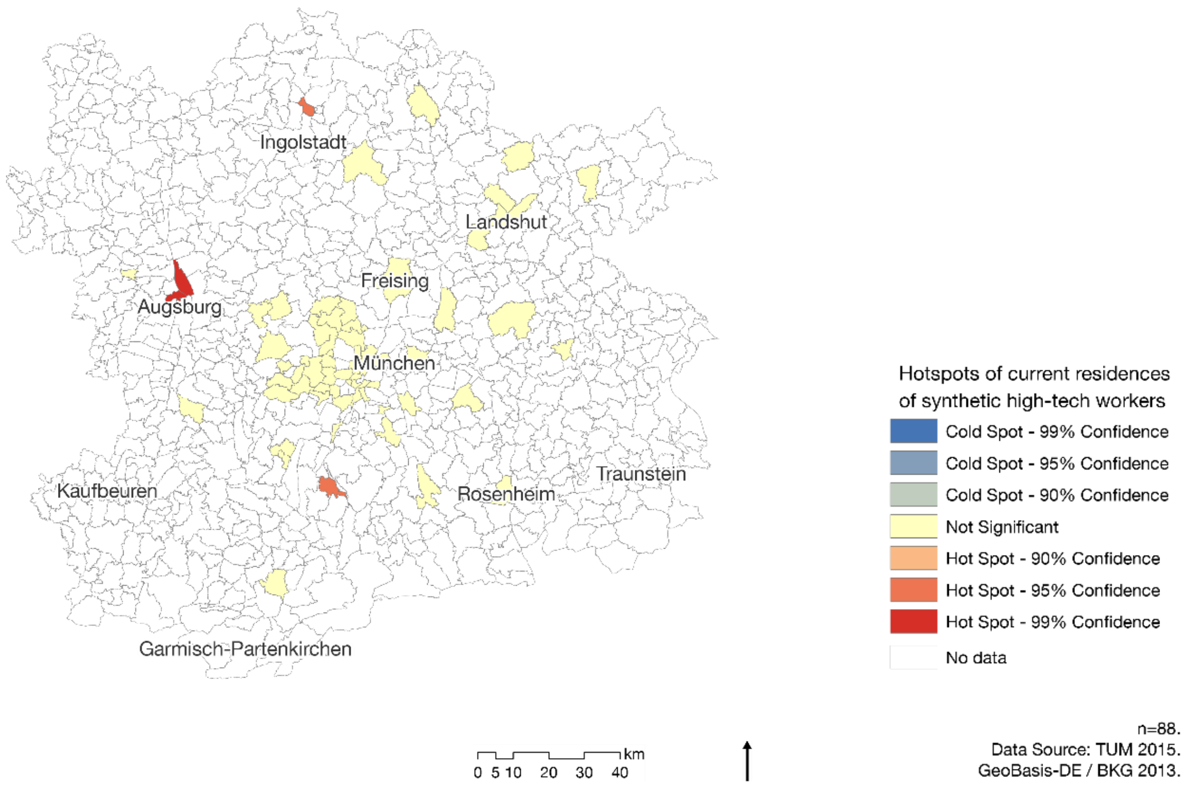


Figure 44. Distribution of residences among synthetic high-tech workers in the MMR.

Hotspots of residential locations in the region

Figures 40-44 show that some of symbolic and synthetic APS-workers' residential hotspot areas are located in the city of Munich. In contrast, there is no statistically significant evidence for the concentration of residences in the city of Munich among analytical and synthetic high-tech workers. In addition, contrary to expectation, other workers' residential locations concentrate most significantly in the city of Munich.

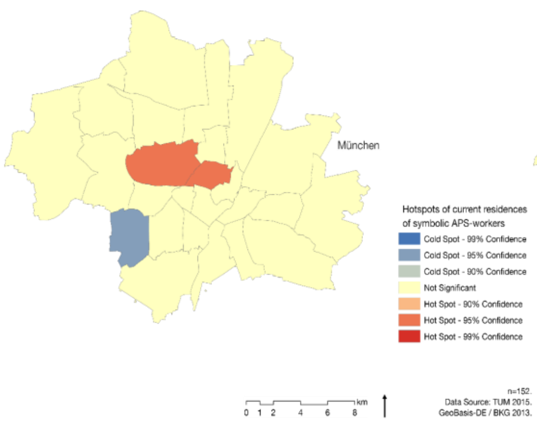


Figure 45. Distribution of residences among symbolic APS-workers in the city of Munich.

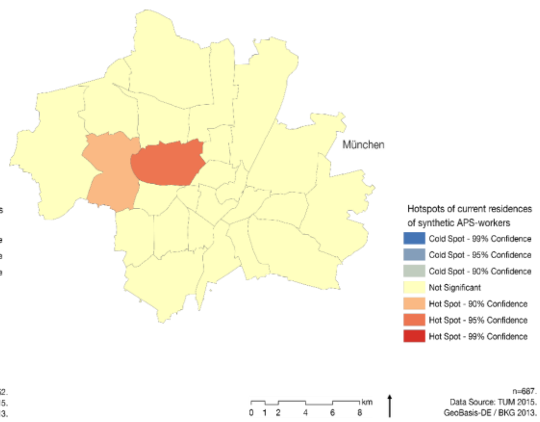


Figure 46. Distribution of residences among synthetic APS-workers in the city of Munich.

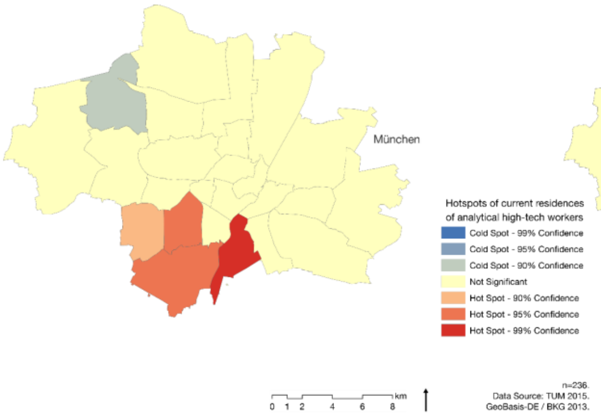


Figure 47. Distribution of residences among analytical high-tech workers in the city of Munich.

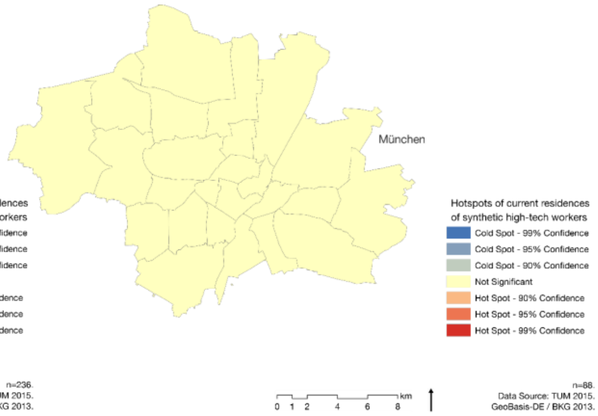


Figure 48. Distribution of residences among synthetic high-tech workers in the city of Munich.

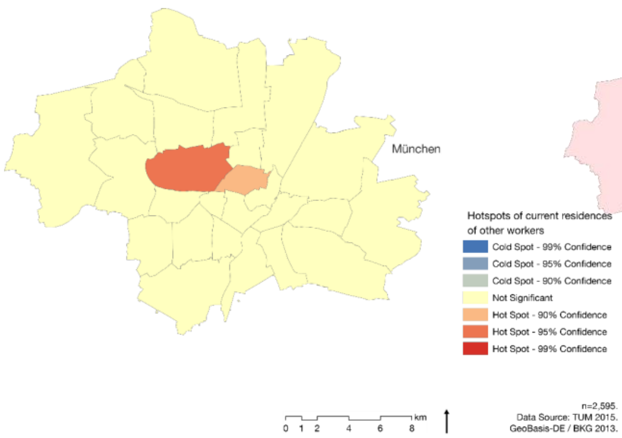


Figure 49. Distribution of residences among other workers in the city of Munich.

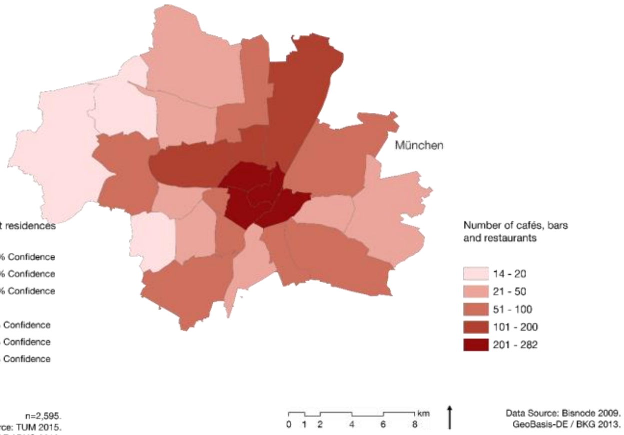


Figure 50. Distribution of residences among cafés, bars and restaurants in the city of Munich.

Hotspots of residential locations in the city of Munich

Since a large proportion of residential locations are within the city of Munich, the hotspot analysis further zooms into the city of Munich (Figures 45-49). Results for degree of concentration of different groups of workers are similar to the regional level. To provide a better understanding of differentiation of the city districts in the city, the spatial maps showing the distribution cafés, bars and restaurants within each district of the city are also included as a reference map for comparison (Figure 50). Symbolic APS-workers' residential hotspot areas are located in the districts of 'Neuhausen' and 'Marxvorstadt' with the highest rent Immobilien Scout GmbH (2016).and the largest number of cafés, bars and restaurants while their residential cold spots areas are districts with the lowest rent and least number of these services. In contrast, there are no hotspots in the residential areas of synthetic high-tech workers. Synthetic APS-workers' hotspot areas are similar to symbolic APS-workers but to a lesser extent regarding the land rent and the number of services. Analytical high-tech workers' hotspot areas have medium levels of services, but the rents in those areas include both high and low levels.

6.2.1.3 Movement patterns (individual movement paths & aggregated pattern)

Individual residential move paths that connect individuals' previous and current residences are depicted in Figure 7A-11A in the appendix. Afterwards, an aggregation of individual movement paths is applied considering the following two aspects: firstly, the residential change between the spatial-functional category, in terms of central areas and non-central areas, is more relevant to the objective of the research than the exact change of geographical location. Secondly, it is not easy to interpret the map with highly overlapping individual movement paths. Accordingly, individual movement paths are aggregated into four types of movement patterns. Remain within central areas (both previous and current residences are located in central areas); Move into central areas (previous residence is outside of central areas but current residence is within central areas); Move out from central areas (previous residence within central areas but current residence is outside of central areas); and remain within non-central areas (both previous and current residences are located outside of central areas).

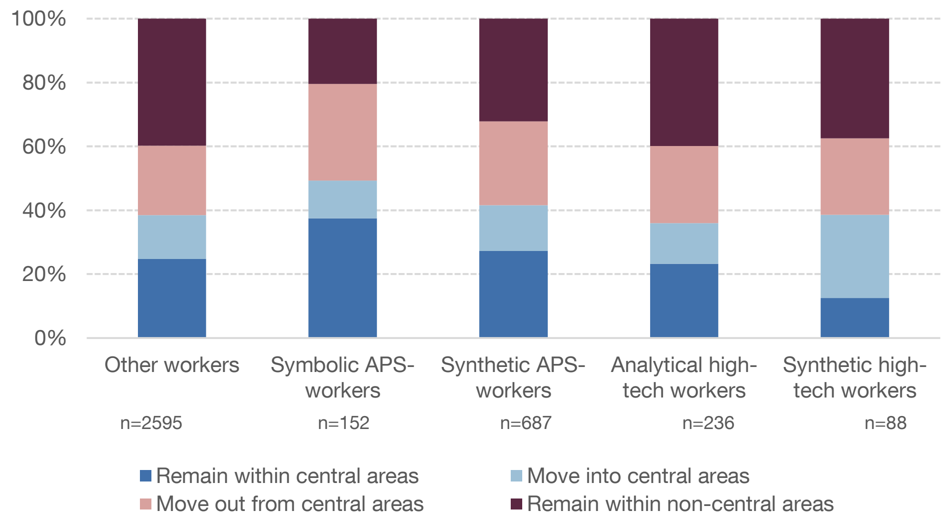


Figure 51. Share of residential movement patterns in relation to 'central areas' among each group of workers.

As indicated in Figure 51, half of symbolic APS-workers either move into central areas or change their residence locations within central areas. The share of individuals' residences remaining within central areas previously and currently continuously decreases from symbolic APS-workers (37.5%), via synthetic APS-workers (27.2%) and analytical high-tech workers (23.3%), to synthetic high-tech workers (12.5%). Almost 40% of symbolic APS-workers live in central areas both previously and currently, whereas the share is only 10% among synthetic high-tech workers. In contrast, the share of individuals' residences remaining within non-central areas previously and currently increases from symbolic APS-workers (20.4%), via synthetic APS-workers (32.2%) and synthetic high-tech workers (37.5%), to analytical high-tech workers (39.8%). 39.8% of other workers' both previous and current residences are located outside of central areas. The first hypothesis is confirmed by these findings.

6.2.2 'Hidden' spatial process: vectors from alternative residence to current residence

The analysis is based on individuals who gave information on their residential alternative during their search process. The first residential alternative is included in the analysis, considering only very few individuals also mentioned their second and third alternative, even though the web-survey allows respondents to include up to three residential alternatives. While the actual move path (originates from previous residence and direct to current residence) describes the actual change of residential location, the spatial vector originating from the alternative residence and directing towards current residence better represents the net influence of individual preference on the spatial concentration or de-concentration process. The former spatial dynamic is more attributable to objective constraining reasons such as the increase of the household size accompanied by dissatisfaction with the current dwelling size, or the demand for housing ownership. In contrast, the latter spatial dynamic between the alternative and current situation is attributable to the individual preferences in residential choice under the same condition or framework. Points represent the current residences and the lines represent the 'invisible movement path' from residential alternative to current residential location; the other end of the line corresponds to the residence alternative.

As expected, distances between the current residence and the unselected residential alternative among all groups of workers are generally small (Figure 52-56). This confirms the finding that individuals search for residences in a geographically focused way (Rodriguez and Rogers 2014: 537; Huff 1986: 209). The final selected residential location does not diverge much from the alternative residence, since both locations orient towards one common important reference point, either workplace or the core city of the metropolitan region. According to the geographical distribution of current residences and alternative residences in Figure 53, it is noticeable that almost all symbolic APS-workers searched/viewed and also live currently within or at least neighboring to the city of Munich. In contrast, despite roughly half of synthetic high-tech workers' residence searches being located in the city of Munich, their current residences are mainly concentrated outside of the city of Munich (Figure 56). In other words, a large part of synthetic high-tech workers eventually 'land' in areas that are more peripheral compared to the alternative situation. The 'invisible movement pattern' of analytical high-tech workers is more similar to synthetic high-tech workers, whereas the 'invisible movement pattern' of synthetic APS-workers is more similar to that of symbolic APS-workers.

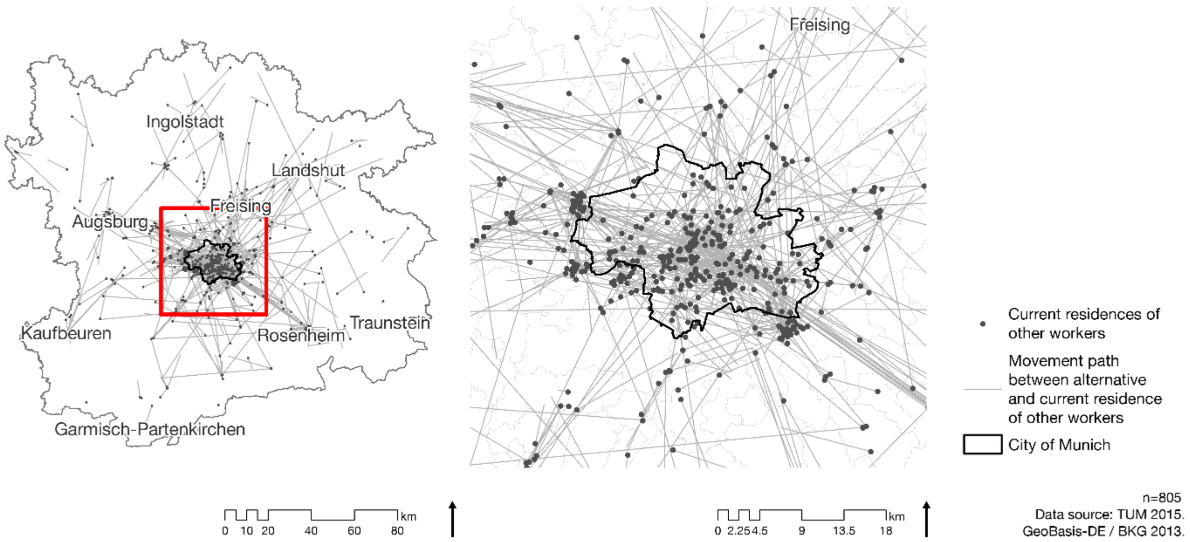


Figure 52. Underlying movement paths of other workers in the metropolitan region of Munich (left) and with a focus on the city of Munich (right).

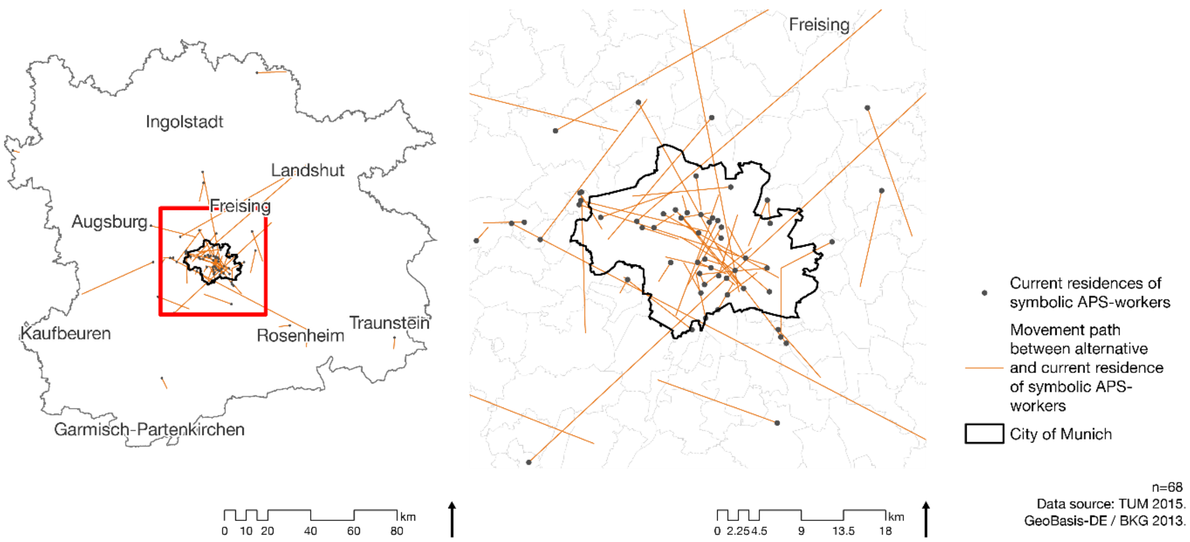


Figure 53. Underlying movement paths of symbolic APS-workers in MMR (left) and with a focus on the city of Munich (right).

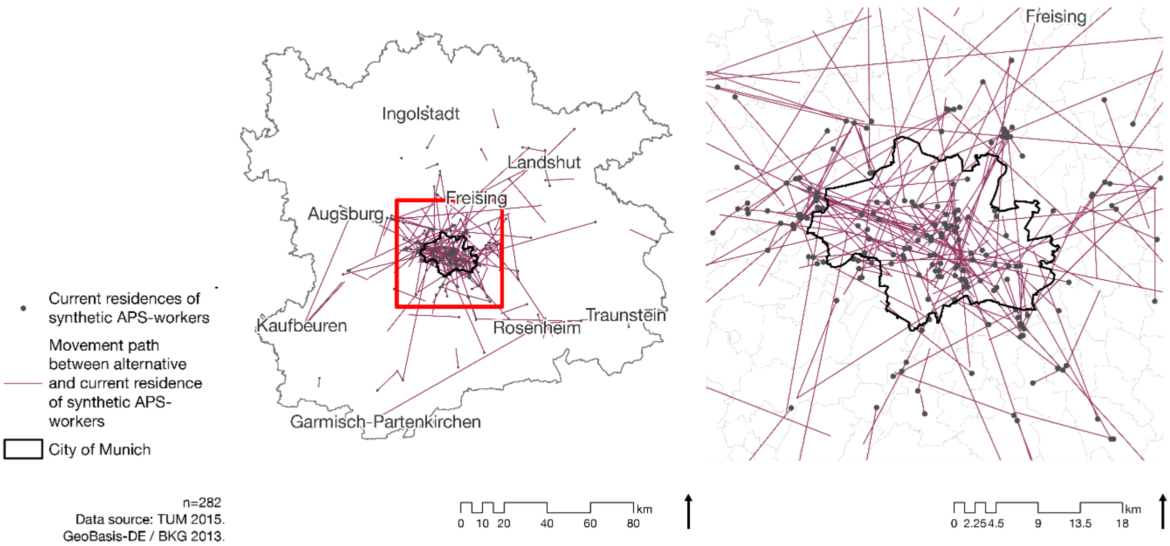


Figure 54. Underlying movement paths of synthetic APS-workers in MMR (left) and with a focus on the city of Munich (right).

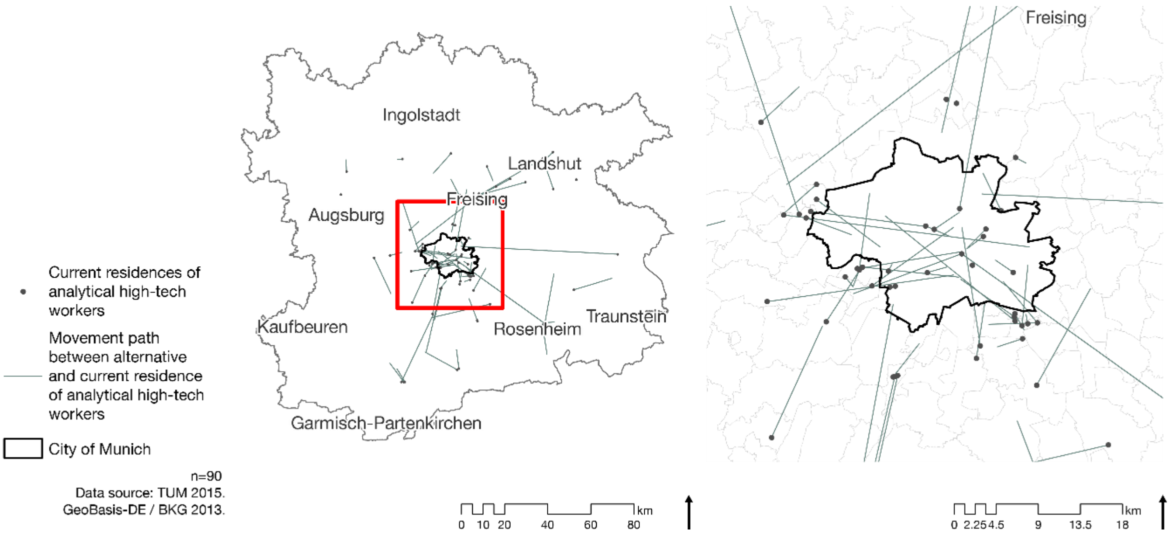


Figure 55. Underlying movement paths of analytical high-tech workers in MMR (left) and with a focus on the city of Munich (right).

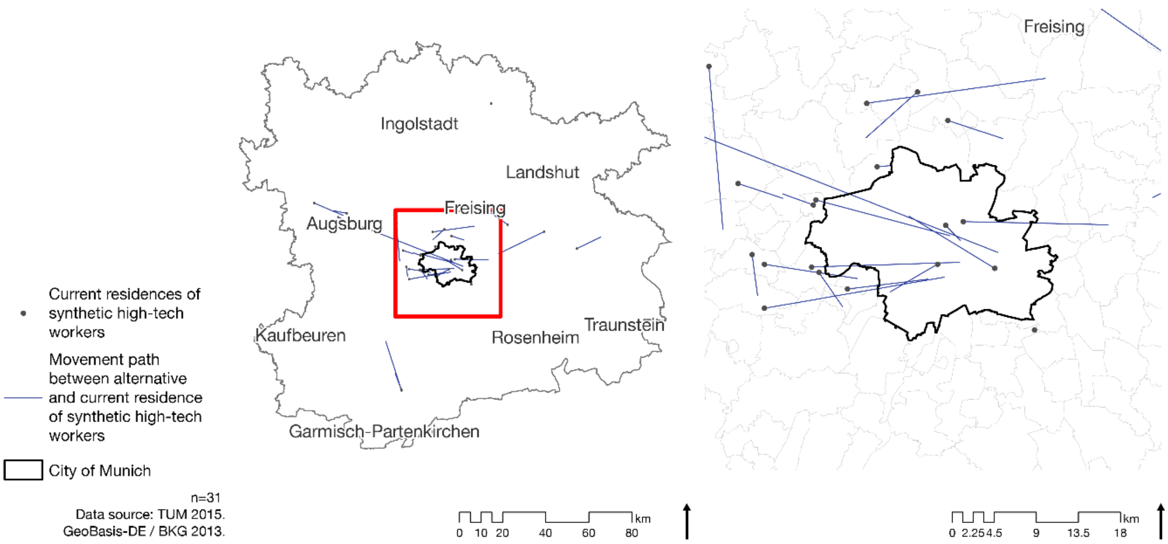


Figure 56. Underlying movement paths of synthetic high-tech workers in the metropolitan region of Munich (left) and with a focus on the city of Munich (right).

6.2.3 Demand for housing ownership

Before a residential move, the share of purchased housing is in general much smaller compared to the share of rented housing among all groups of workers (Figure 57). The share of individuals owning homes is slightly larger among synthetic APS-workers and synthetic high-tech workers than among other groups of workers.

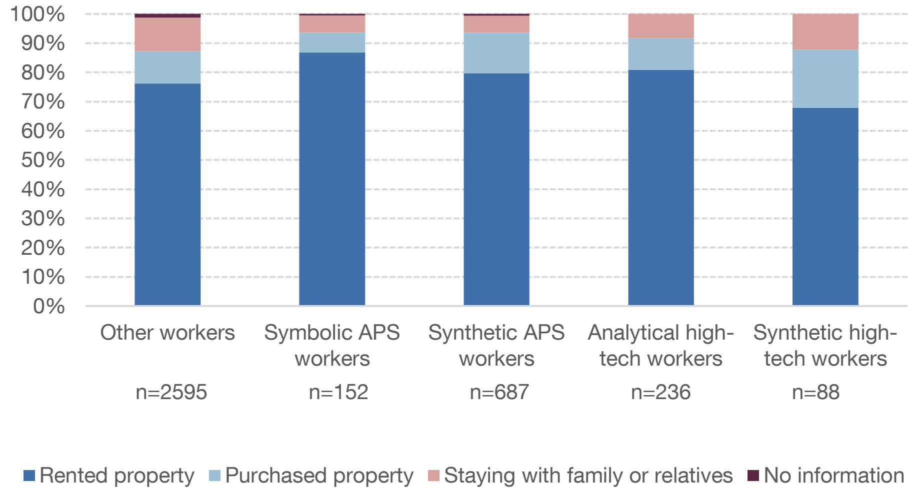


Figure 57. Shares of individuals with housing ownership among each group of workers before the residential move.

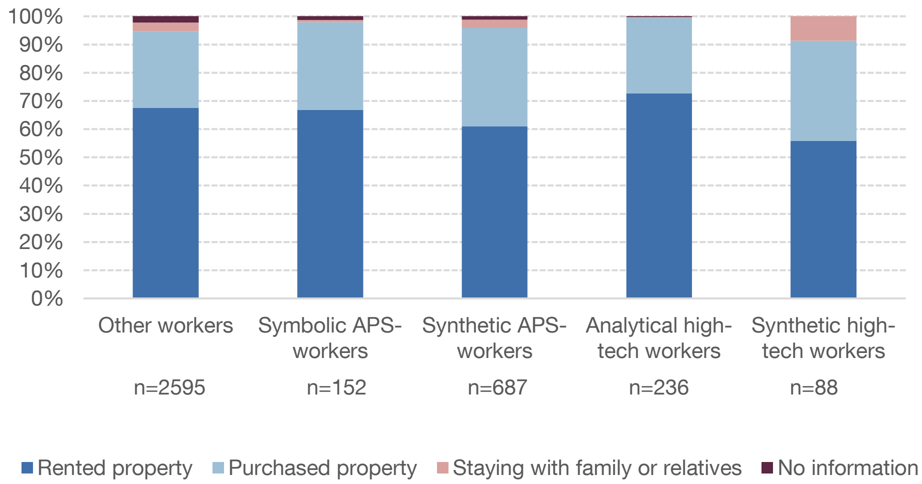


Figure 58. Shares of individuals with housing ownership among each group of workers after the residential move.

After a residential move, housing ownership in general increases among each group of workers (Figure 58). Symbolic APS-workers with the lowest share of housing ownership previously have the largest increase in housing tenure from rental to purchase. Nevertheless, the difference to synthetic high-tech workers still obtains. Whereas the share of housing ownership among synthetic high-tech workers and synthetic APS-workers is roughly 35.5% and 34.9%, the shares among symbolic APS-workers and analytical high-tech workers are respectively 31.1% and 26.7%.

6.2.4 Option of home office

The web survey also contains information on whether people sometimes work from home away from their physical fixed workplace. It was found that more than 30% of analytical high-tech workers and synthetic APS-workers, and 25% of symbolic APS-workers in some cases work from home, whereas the share is only 20% among synthetic high-tech workers. This is as expected since the tasks for synthetic APS-workers, analytical high-tech workers and symbolic APS-workers are relatively more independent of fixed workplaces, whereas tasks for synthetic high-tech workers depend more on certain equipment and facilities.

6.3 Statistical likelihood of residing in central areas

All the above spatial analyses present the spatial outcomes of residential location, which are attributable to a range of factors including socio-demographic, spatial structural factors as well as the influence of knowledge base. To investigate the independent influence of knowledge base, the regression model that controls for other relevant factors is further applied here. Here the current residential location is analyzed.

6.3.1 Distribution with respect to central or non-central areas

Compare knowledge workers and other workers

Figure 59 does not indicate an apparent different distribution of residences in terms of central and non-central areas among knowledge workers and other workers. Among either group, 40% of residences are located within central areas, whereas 60% of residences are within non-central areas. This prompts further investigation of whether there is heterogeneity within residential location preferences among different groups of knowledge workers (elaborated in detail below).

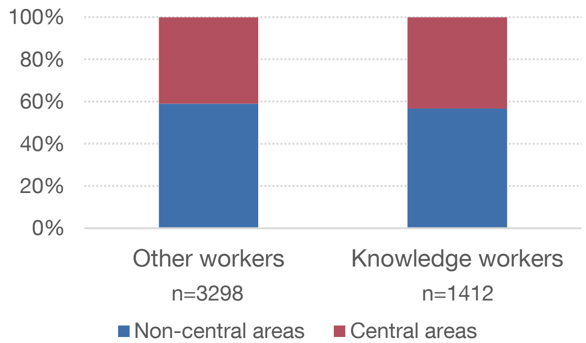


Figure 59. Distribution of residential locations in relation to central areas among knowledge workers and other workers.

Compare workers in high-tech industries and APS sectors

As shown in Figure 60, a slight difference is apparent in the distribution of residential locations among workers in different employment sectors. Among workers who are employed in APS sectors, the share of individuals who live in central areas is 45%, whereas the share is only 38% among high-tech workers. The slight difference might result from different spatial logics between high-tech and APS firms, which is not the only aspect that influences individuals' residential choices. There might be other more relevant factors underlying the decision-making process of residence location, which will be analyzed in the next section.

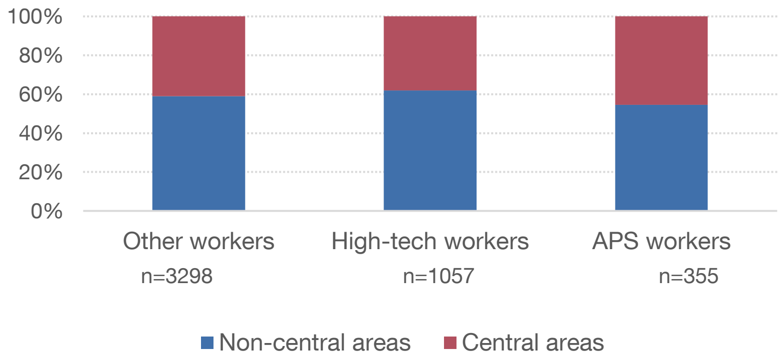


Figure 60. Distribution of residential locations in relation to central areas among workers in high-tech industries and APS sectors, and other workers.

Comparison of analytical high-tech workers, synthetic high-tech workers, synthetic APS-workers, and symbolic APS-workers

In addition, the residential locations among different groups of knowledge workers categorized by the dominant knowledge base are also compared. As indicated in Figure 61, residential location patterns, in terms of residence within or outside 'central areas', vary among different groups of knowledge workers. Within the sample, there is an apparent difference between symbolic APS-workers and synthetic high-tech workers. Half of symbolic APS-workers currently live in central areas, whereas the share is only 31% among synthetic high-tech workers. Around 40% of analytical high-tech workers, synthetic APS-workers and other workers live in central areas.

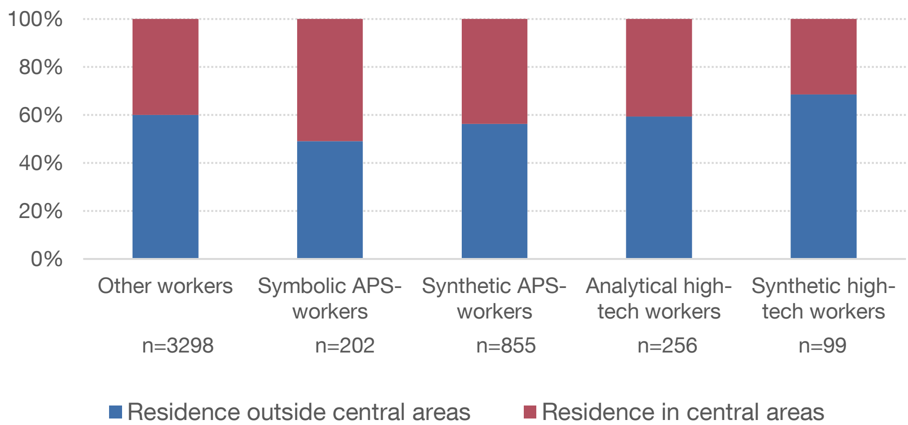


Figure 61. Distribution of residential locations in relation to central areas among each group of workers.

6.3.2 The impact of knowledge base in residential location choice

Distribution of the socio-demographic variables

The aforementioned variety regarding residential location might relate to different job locations and mobility preference or resource. Firstly, as expected, a large portion of firms using symbolic knowledge is located in central areas. 76% of symbolic APS-workers' workplaces are located in central areas, whereas the share is only 49% for synthetic high-tech workers (Figure 62). Secondly, the share of individuals with auto affinity is less among symbolic APS-workers than that of synthetic high-tech workers (Figure 63). Thirdly, the level of ownership of private car is lower among symbolic than that of synthetic high-tech workers (Figure 64).

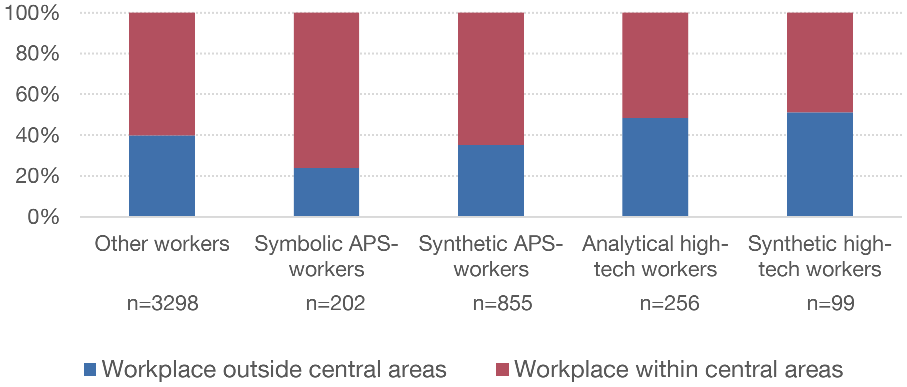


Figure 62. Distribution of workplace locations among each group of workers.

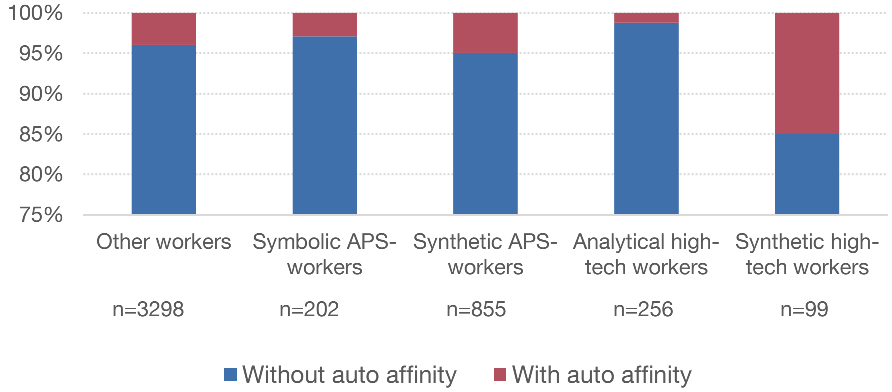


Figure 63. Distribution of auto affinity among each group of workers.

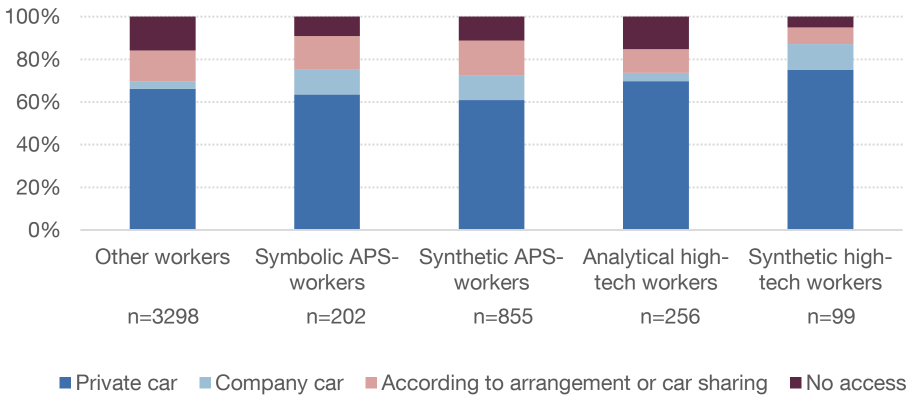


Figure 64. Distribution of car ownership among each group of workers.

Basic model with the variable of knowledge worker group

Spatial distributions of residences shown above are descriptive results. Residential location might relate closely to the socio-demographics and the workplace location. Hence, to identify the specific impact of knowledge base on the residential location, these conventional socio-demographic factors and workplace location should be firstly controlled before introducing the knowledge base in the integrated model. Statistically significant estimates at a level of 0.05 are marked with an asterisk. To facilitate reading, those estimates that are explained in detail are highlighted in bold. Model 1 shows that the largest positive correlation exists between job centrality and residential centrality (Table 6). Given the job is located within central areas, individuals in general are more likely to reside in central areas. Based on model 1, the categorical variable of knowledge worker group is added in model 2 (Table 6). R square increases slightly from 0.190 in model 1 to 0.193 in model 2. The correlation between the categorical variable of knowledge worker group and their residential location centrality is insignificant. This suggests that residential location centrality, in terms of location within or outside of central areas, is largely explained by those aforementioned factors such as socio-demographic variables, job location, auto affinity, and car ownership.

Basic model with knowledge worker group interacting with income and workplace location

The analysis now continues by focusing on the influence of the knowledge worker group in certain situations, such as certain job location centrality and certain income level. Based on model 2, the interaction term 'job location*knowledge worker group' is further added. Model 3 indicates that when job location is outside of central areas, symbolic APS-workers are still more likely to reside in central areas, compared to synthetic high-tech workers (Table 6). This is consistent with the finding that nearly 45% of symbolic APS-workers regard the image or atmosphere of the location ('Ortsbild' in German) as important, whereas the share is only around 38% for other groups. To summarize, symbolic APS-workers allocate a central "spatial anchor point" (Chaix et al. 2012: 441), either residence or workplace, close to the poles of knowledge exchanges (Brake 2015: 18-19). In addition, Felsenstein (2002) also reaches the similar conclusion that highly skilled workers in high-tech industries exert pressure on land at the metropolitan fringe, irrespective of the place of work (Felsenstein 2002: 664). Similarly, the correlation between knowledge worker group and the residential location at certain income levels is further examined by adding the interaction term 'income level*knowledge worker group' in model 4 (Table 6). It is noticeable that among medium-income households, symbolic APS-workers are more likely to live in central areas compared to synthetic high-tech workers. However, among low-income households, symbolic and synthetic APS-workers are less likely to live in central areas than synthetic high-tech workers are.

*Table 6. Results of binary residential location choice modelling (Authors' own calculation; * indicates 0.05 significant level; Odds ratio marked in bold are explained in detail in the text; n= 5142).*

	Exp(B_n) / Odds ratio			
Variables	Model 1	Model 2	Model 3	Model 4
Constant	0.12*	0.11*	0.05*	0.08*
Household type: Family (ref)				
Single person	1.89*	1.88*	1.88*	1.87*
Single parent	1.78*	1.75*	1.74*	1.78*
Two-person household	1.42*	1.41*	1.41*	1.41*
Household income: Medium income (ref)				
Lowest income	0.87	0.88	0.88	3.54
Highest income	1.03	1.02	1.02	1.92
Gender: Male (ref)				
Female	0.93	0.95	0.94	0.95
Education level: With university degree (ref)				
Without university degree	0.64*	0.65*	0.65*	0.65*
Auto affinity: with (ref)				
without auto affinity	2.14*	2.14*	2.12*	2.17*
Job centrality: peripheral job (ref)				
Central job location	**2.96***	2.94*	8.85*	2.93*
Car ownership: Private car (ref)				
Company car	1.34*	1.30	1.29	1.30
According to need	1.37*	1.37*	1.38*	1.37*
Car sharing	4.03*	4.00*	4.07*	4.01*
No car	2.81*	2.83*	2.84*	2.82*
Subgroups of population: high-tech workers (ref)				
Other workers		1.02	2.28	1.48
Analytical workers		0.97	2.46	1.12
Symbolic KW		1.40	**2.97***	**2.21***
APS KW		1.16	2.16	1.77
Subgroups interact with workplace centrality				
Other workers by Central workplace			0.31*	
Analytical workers by Central workplace			0.25*	
Symbolic KW by Central workplace			0.34	
APS KW by Central workplace			0.40	
Subgroups interact with income level				
Other workers by lowest income level				0.25
Analytical workers by lowest income level				0.58
Symbolic KW by lowest income level				**0.11***
APS KW by lowest income level				**0.17***
Other workers by highest income level				0.52
Analytical workers by highest income level				0.72
Symbolic KW by highest income level				0.51
APS KW by highest income level				0.49
Nagelkerke R Square	**0.190**	**0.193**	**0.210**	**0.215**

6.3.3 Different residential location choice among each group of workers

Lastly, results of residential location modelling for each group of workers are here presented. As shown in Table 7, symbolic and synthetic APS-workers in single-person households tend to live in central areas as opposed to family households. Synthetic APS-workers who are single parents tend to have an even larger probability of living in central areas than single-person households. Interestingly, results suggest that synthetic high-tech workers in two-person households are more likely to live in central areas than family households (at the significance level of only 0.10). Moreover, symbolic APS-workers, synthetic APS-workers and synthetic high-tech workers' likelihood of living in central areas is correlated closely with the household income. At a low-income level, symbolic APS-workers' probability of living in central areas is significantly smaller compared to the medium income level. In contrast, analytical high-tech workers with a low-income level have a larger tendency to live in central areas compared to those with a medium income level. The high-income synthetic high-tech workers' probability of residing in central areas is even larger than that of individuals with a medium-income level. Lastly, the analysis finds that the availability of a company car has a positive influence on synthetic APS-workers' residential location choice of central areas, whereas it does not generate influences on other groups of knowledge workers.

*Table 7. Results of binary logistic regression regarding residential choice among each group of workers (Author's own calculation; * indicates 0.05 significant level).*

Variables	Other workers (n=3298)	Analytical worker (n=256)	Coefficients Symbolic worker (n=202)	APS worker (n=855)	High-tech workers (n=99)
Constant	-2.52*	-1.83	-2.80*	-2.18*	-6.00*
Household type: Family (ref)					
Single person	0.68*	-0.34	**1.25***	**0.82***	1.11
Single parent	0.40	0.75	1.01	**1.60***	-2.28
Two-person household	0.44*	0.71	0.84	0.18	**0.37***
Shared-living apartment	0.17	0.01	0.93	0.57	0.16
Household income: Medium income (ref)					
Low income	0.16	**1.69***	**-1.06***	**-0.76***	2.60
High income	-0.07	0.36	0.14	0.08	**0.86***
Gender: Male (ref)					
Female	-0.12	-0.62*	0.48	0.20	-0.36
Education level: With university degree (ref)					
Without university degree	-0.56*	-0.55	-0.90	-0.35	0.67
Auto affinity: auto affine (ref)					
No auto affinity	1.03*	0.27	1.17	0.65	2.12
Job centrality: peripheral job (ref)					
Central job location	1.13*	0.56*	1.21*	1.21*	2.16*
Car ownership: Private car (ref)					
Company car	0.36	0.724	-0.46	**0.72***	-0.71
According to need	0.40*	1.09	0.48	0.08	0.19
Car sharing	1.73*	0.56	1.56*	1.07*	-1.93
No car	1.02*	1.83*	0.72	0.93*	2.87
Nagelkerke R Square	**0.213**	**0.253**	**0.242**	**0.201**	**0.446**

6.4 Summary of key findings

- Commutes among synthetic high-tech workers are in general longer than that among other groups of workers. In addition, there is an increase of the commute after joint change of residence and workplace among synthetic high-tech workers, while a large share of other groups of workers reduce the commute. Commute path among synthetic high-tech workers is mainly between non-central areas, whereas commute path among symbolic APS-workers is mainly among central areas.
- The overall distribution of residential locations are more central-areas oriented or city of Munich oriented among symbolic APS-workers than synthetic high-tech workers. A larger share of symbolic APS-workers' residential locations remain in central areas, whereas synthetic high-tech workers remain in non-central areas.
- In spite of general de-concentration after a residential move, the degree of de-concentration varies: minimal among symbolic APS-workers, largest among synthetic high-tech workers; analytical high-tech workers and synthetic APS-workers are positioned in between.
- Synthetic high-tech workers rank first regarding the share of individuals with housing ownership among all groups of workers. However, synthetic high-tech workers with high-income level also choose central areas compared to those with median income level.
- Results confirm that classical factors, like cost and size of dwelling, are still important considerations in knowledge workers' residential choices. Therefore, the phrase 'tend to' is chosen in the first hypothesis to indicate clearly the specific influence of knowledge base.
- Albeit to a limited degree, knowledge base does appear to generate extra influence on the residential location choice when socio-demographic variables, workplace location, as well as the mobility preference are controlled for in the logistic regression model.

7 Underlying trade-offs and revealed preferences in residential location choice

The previous chapter introduced the spatial outcomes of residential location choice. This chapter continues to investigate the underlying trade-off processes during residential decision-making, namely which residential attributes have been upgraded and which other residential attributes have been simultaneously sacrificed. The first section will introduce the motivations for moving as well as the importance assessed for each residential attribute. It continues with an overview of the current attributes of their selected residences. The last two sections will focus on identifying distinct preferences for certain residential attributes among different groups of knowledge workers with the revealed preference approach. Both individually based as well as aggregated preferences are analyzed.

7.1 Understanding knowledge workers' actual spatially-related needs and demands via their motivations, importance assessment, and leisure-activity pattern

This section will firstly summarize the frequently mentioned reasons for residential move or job changes. Afterwards, the importance assessed for each attribute near the residence and workplace are analyzed. This part will end with an overview of the leisure activity pattern.

7.1.1 Motivations for moving residence and changing jobs

Reasons for moving residence

While 24 specific reasons for moving are included in the web-survey, only the first five most frequently mentioned reasons are listed. It is noticed that most frequently mentioned reasons are related to the dwelling size, an increase in household members, the facilities and qualities of the dwelling, housing ownership, as well as housing cost (Table 8).

Table 8. Five most important reasons of residential move among each group of workers (Author's own calculation).

Reasons among other workers (n=2595)	**Percentage**
▪ Unsatisfactory with the current dwelling size	34.7%
▪ Inadequate facilities and quality of the dwelling	25.1%
▪ Demand of housing ownership	22.6%
▪ Unsatisfactory with the surrounding of the neighborhood (e.g. noise, safety)	21.4%
▪ More household members in the household	20.9%

Reasons among analytical high-tech workers (n=236)	**Percentage**
▪ Unsatisfactory with the current dwelling size	34.3%

▪ Inadequate facilities and quality of the dwelling	30.8%
▪ Demand of housing ownership	25.8%
▪ More household members in the household	21.7%
▪ Current housing cost is too high	21.3%

Reasons among symbolic APS-workers (n=152)	**Percentage**
▪ Unsatisfactory with the current dwelling size	36.4%
▪ Demand of housing ownership	33.3%
▪ More household members in the household	31.2%
▪ Unsatisfactory with the surrounding of the neighborhood (e.g. noise, safety)	28.4%
▪ Inadequate facilities and quality of the dwelling	21.8%

Reasons among synthetic APS-workers (n=687)	**Percentage**
▪ Unsatisfactory with the current dwelling size	37.1%
▪ Demand of housing ownership	32.5%
▪ Inadequate facilities and quality of the dwelling	28.4%
▪ More household members in the household	24.4%
▪ Current housing cost is too high	18.9%

Reasons among synthetic high-tech workers (n=88)	**Percentage**
▪ Unsatisfactory with the current dwelling size	38.8%
▪ Distance to the workplace is too long	28.3%
▪ Demand of housing ownership	27.9%
▪ Inadequate facilities and quality of the dwelling	27.7%
▪ Current housing cost is too high	21.2%

The dissatisfaction with the current dwelling size is bundled together with more members in the household among symbolic APS-workers, analytical high-tech workers, synthetic APS-workers and other workers. However, this is not the case for synthetic high-tech workers. 'Distance to the workplace is too long' appears only among synthetic high-tech workers as the five most frequently mentioned reasons. Only symbolic APS-workers and other workers mentioned frequently mentioned 'Dissatisfaction with the surrounding neighborhood (e.g. noise, safety)' as the motivation for moving their residences.

Reasons for changing jobs

In parallel, shares of individuals who state the reasons for changing job locations are calculated and only the five most frequently mentioned reasons are shown in Table 9. Similar to reasons for moving residence, the most important reason for changing job is related to the job itself, specifically better career prospects. In contrast, the services and accessibility nearby only play secondary roles in driving individuals to change their jobs. Apart from job prospects, roughly 10% to 15% of individuals mentioned the change of residence location as the reason for changing jobs among each group of workers, which confirms the previous argument in Chapter 2 that the causality actually also runs from the residence to the workplace. While synthetic APS-workers, synthetic high-tech and analytical high-tech workers mention one of the main reasons for changing job is the large distance to the main workplace, symbolic APS-workers and other workers did not mention it.

Table 9. Five most important reasons of changing jobs among each group of workers Author's own calculation).

Reasons of changing job locations among other workers (n=2543)	**Percentage**
▪ Better career perspective	44,7%
▪ Start working career	22,6%
▪ Other reasons	18,9%
▪ Intra-organizational change of the workplace location	16,1%
▪ Change of residence location	14,0%

Reasons of changing job locations among analytical high-tech workers(n=197)	**Percentage**
▪ Better career perspective	37,0%
▪ Start working career	33,6%
▪ Distance to the main workplace is too long	16,6%
▪ Other reasons	14,6%
▪ Change of residence location	14,1%

Reasons of changing job locations among symbolic APS-workers (n=169)	**Percentage**
▪ Better career perspective	54,5%
▪ Start working career	17,6%
▪ Change of residence location	16,9%
▪ Other reasons	16,7%
▪ Intra-organizational change of the workplace location	12,9%

Reasons of changing job locations among synthetic APS-workers (n=641)	**Percentage**
▪ Better career perspective	56,8%
▪ Intra-organizational change of the workplace location	18,8%
▪ Start working career	17,1%
▪ Change of residence location	13,6%
▪ Distance to the main workplace is too long	13,5%

Reasons of changing job locations among synthetic high-tech workers (n=86)	**Percentage**
▪ Better career perspective	55,9%
▪ Intra-organizational change of the workplace location	24,7%
▪ Start working career	17,3%
▪ Distance to the main workplace is too long	14,9%
▪ Change of residence location	14,0%

7.1.2 Importance assessment of certain attributes related to residence and workplace location

Importance assessment of certain attributes for residence

The importance assessment of residential attributes among symbolic APS-workers and synthetic high-tech workers differs widely (Figure 68a and 68b). 24% of symbolic APS-workers regard cultural and gastronomic services as important criteria for residential locations, whereas the share is only slightly larger than 10% among synthetic high-tech workers. More than 44% of symbolic APS-workers regard the attractiveness of the locality or neighborhood as important, whereas 37% of synthetic high-tech workers mentioned its importance. Whereas the share is more than 70% among symbolic APS-workers regarding the availability of public transport services as important, the share is only 43% among synthetic high-tech workers. Among symbolic APS-workers, a walking and cycling-friendly environment is even more important than the quality and facilities of the dwelling itself. This partly confirms the second hypothesis that the locational characteristic of the dwelling is more important than the dwelling itself among symbolic APS-workers. Hence, symbolic APS-workers have a larger willingness to pay for these characteristics, namely trade off residential costs for better locations.

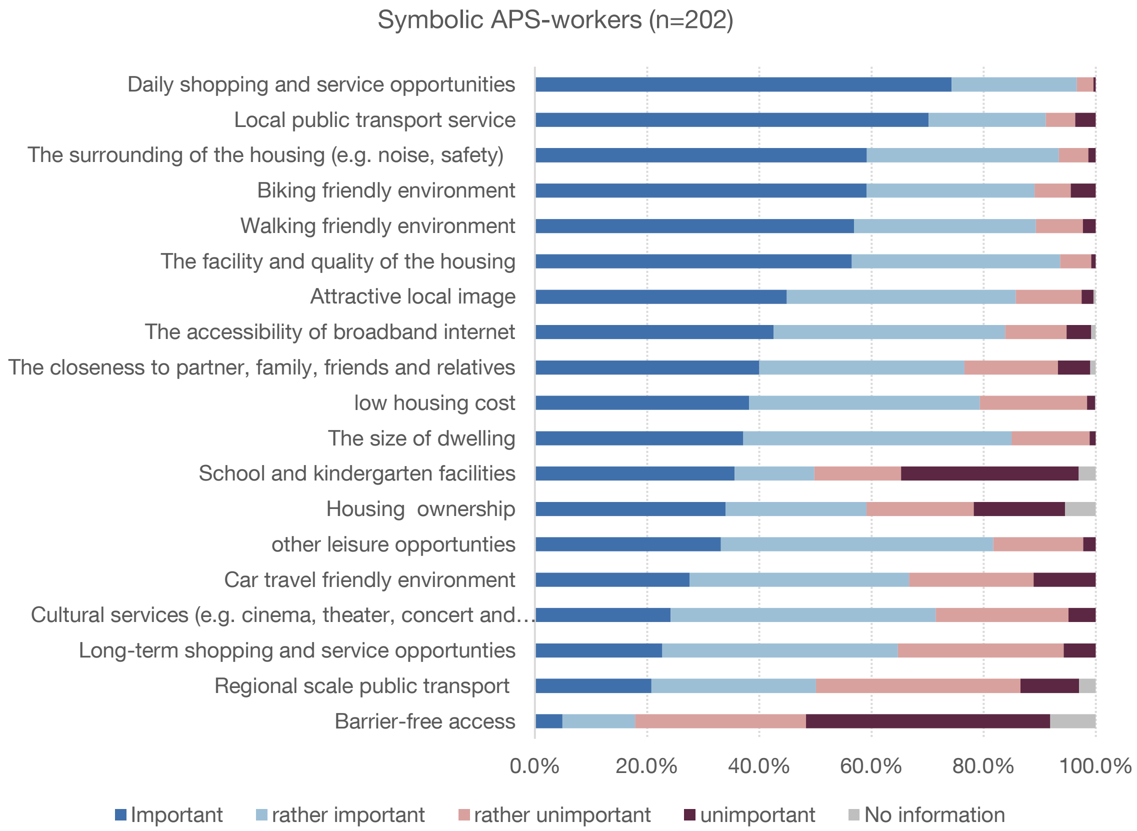


Figure 65. Importance assessment of residential attributes among symbolic APS-workers.

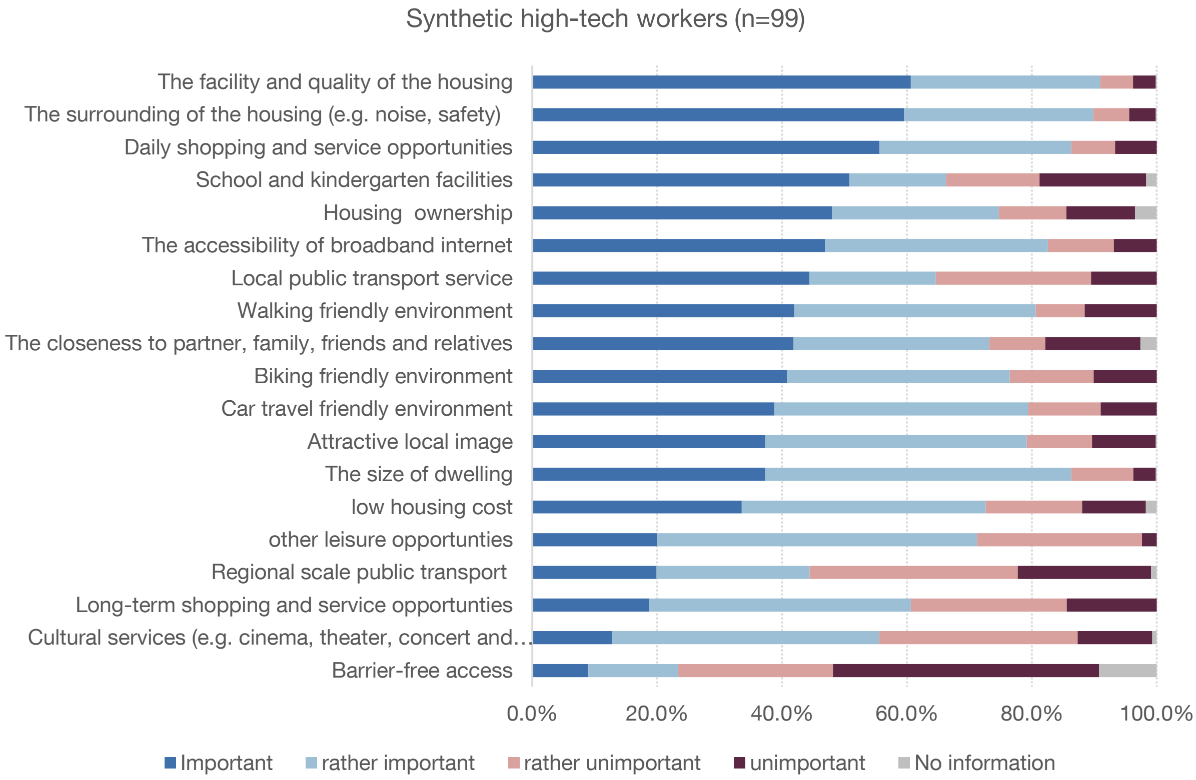


Figure 66. Importance assessment of residential attributes among synthetic high-tech workers.

In contrast, nearly half of synthetic high-tech workers regard housing ownership as important, while the share is 34% among symbolic APS-workers. The facilities and quality of the dwelling ranks as the most important attribute among synthetic high-tech workers' residential choice, whereas it is only accounted as the sixth important most aspect among symbolic APS-workers. In addition, more synthetic high-tech workers mention the importance of the noise and safety level near the residence, as well as the school facilities compared to other groups. Hypothesis 2 is to some extent supported since the dwelling itself is assessed as more important than the location of the residence among synthetic high-tech workers. This fits in with the finding in the following section that they have a larger possibility of sacrificing commute to achieve a better residence.

Compared to symbolic APS-workers and synthetic high-tech workers, synthetic APS-workers, analytical high-tech workers, and other workers do not display very apparent preferences during their assessment (Figures 65 and 69). The facilities and quality of the dwelling ranks as the fourth most important factor, which places them between synthetic high-tech workers (the first) and symbolic APS-workers (the sixth). In addition, the share of these three groups of workers mentioning the importance of housing ownership lies between symbolic APS-workers (30%) and synthetic high-tech workers (50%). Moreover, their importance assessment (nearly 20%) of cultural and gastronomic services also lies in between symbolic APS-workers (24%) and synthetic high-tech workers (13%).

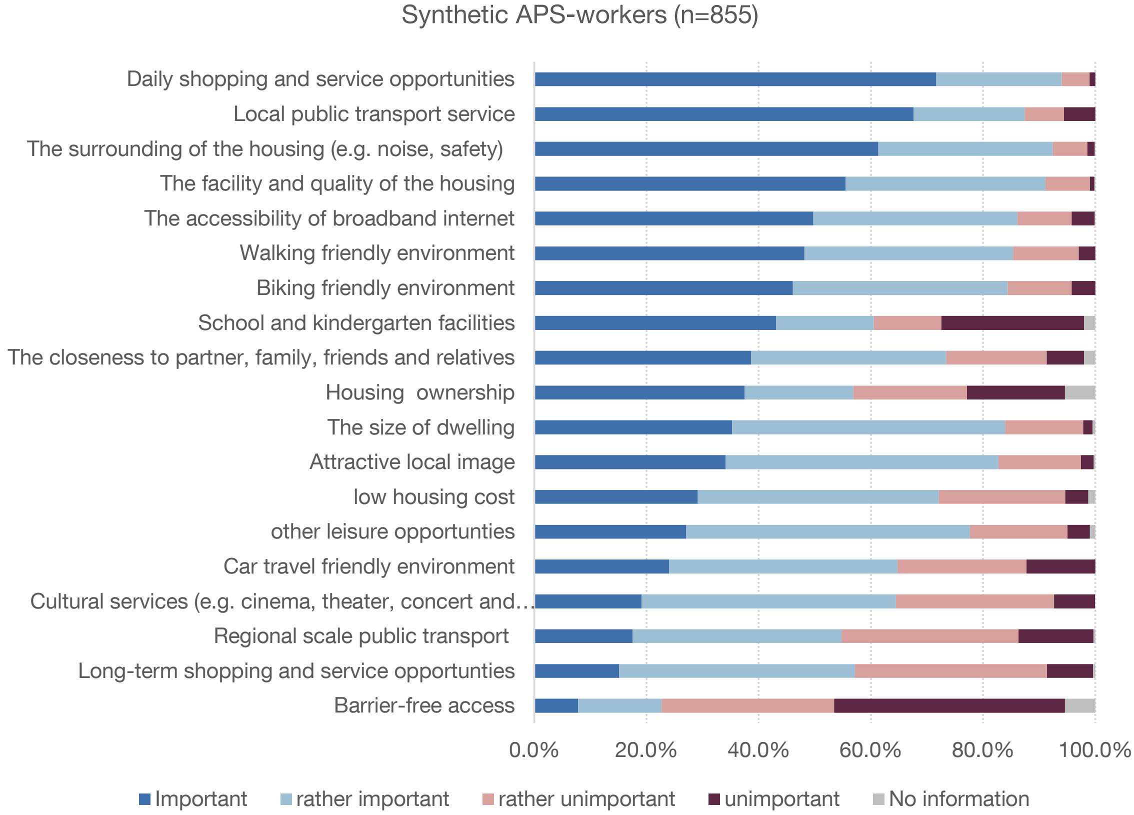


Figure 67. Importance assessment of residential attributes among synthetic APS-workers.

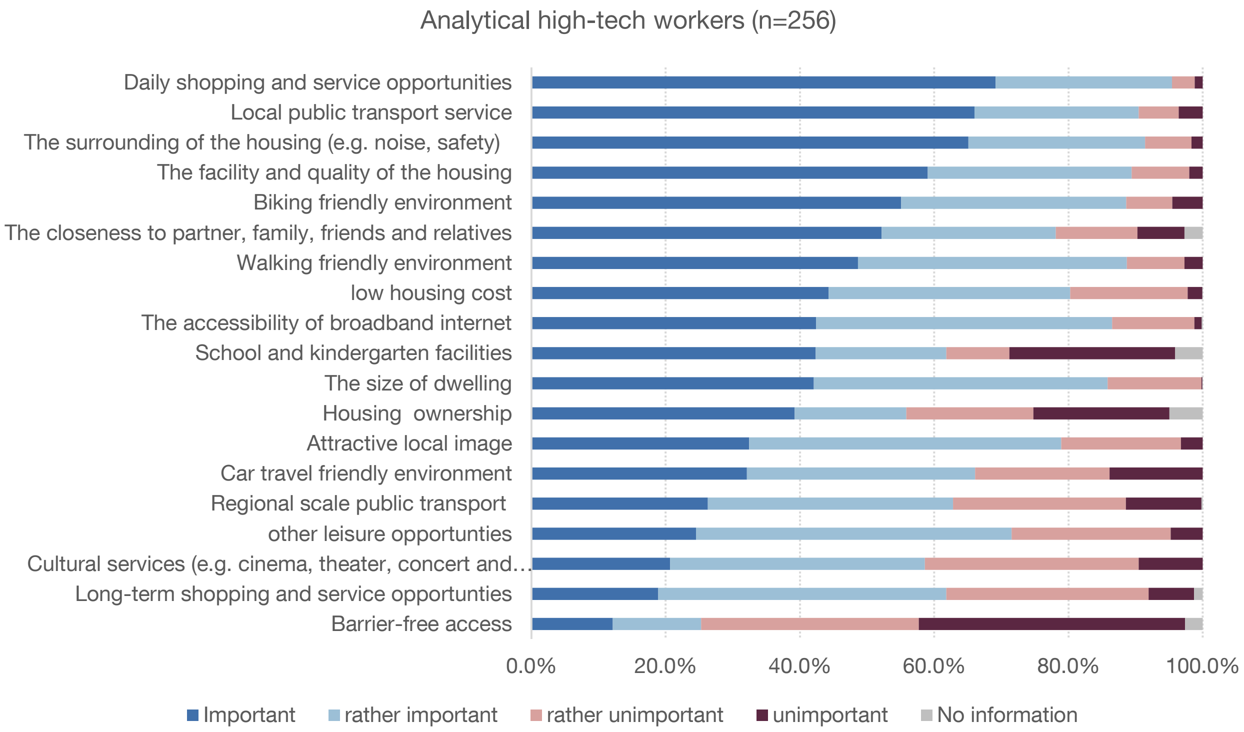


Figure 68. Importance assessment of residential attributes among analytical high-tech workers.

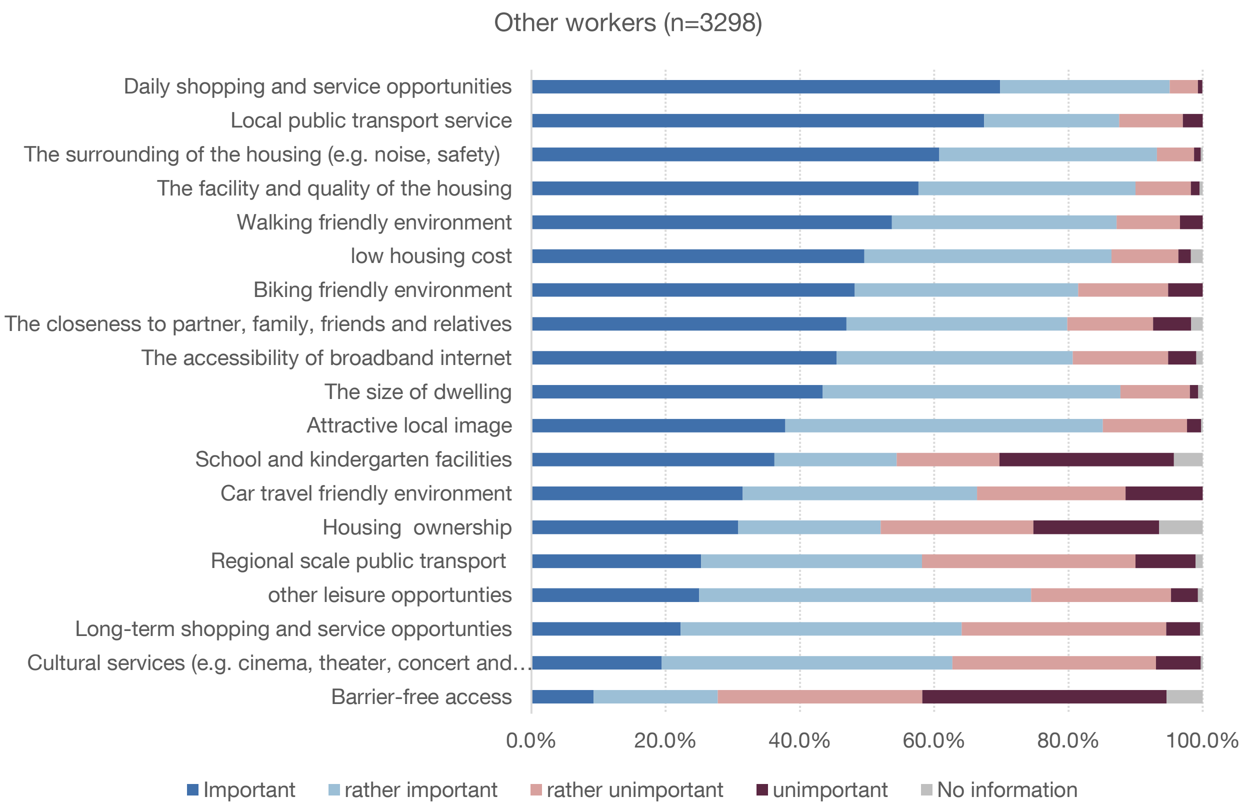


Figure 69. Importance assessment of residential attributes among synthetic APS-workers.

Importance assessment of certain attributes for workplace

The analysis of importance assessment of certain attributes at workplace is presented in Figures 70-74. Only among synthetic high-tech workers is the share of individuals who report the importance of accessibility using private car to reach the workplace larger than the share who rate the importance of public transport. More than 70% of all groups of workers other than synthetic high-tech workers regard the accessibility of public transport to reach their workplaces as important. Among analytical high-tech workers and symbolic APS-workers, the share of respondents rating the importance of accessibility for cycling to the workplace is respectively 50% and 43%. In contrast, only 20% of synthetic high-tech workers and 33% of synthetic APS-workers mentioned the importance of cycling as the commute mode. Since cycling here has its highest threshold, the importance of accessibility with cycling might indirectly reflect their preference for job-housing spatial proximity. Regarding cultural and gastronomic services, very few (less than 1%) of synthetic high-tech workers mentioned its importance. In contrast, almost 10% of symbolic APS-workers regard it as important at the workplace, even more important compared to school and kindergarten facilities, long-term shopping and service opportunities, and other leisure activities. When comparing the assessed importance of each locational criteria at residence and workplace, it is revealed that more individuals mentioned the availability of services and accessibility to other leisure activities near their residence than workplace.

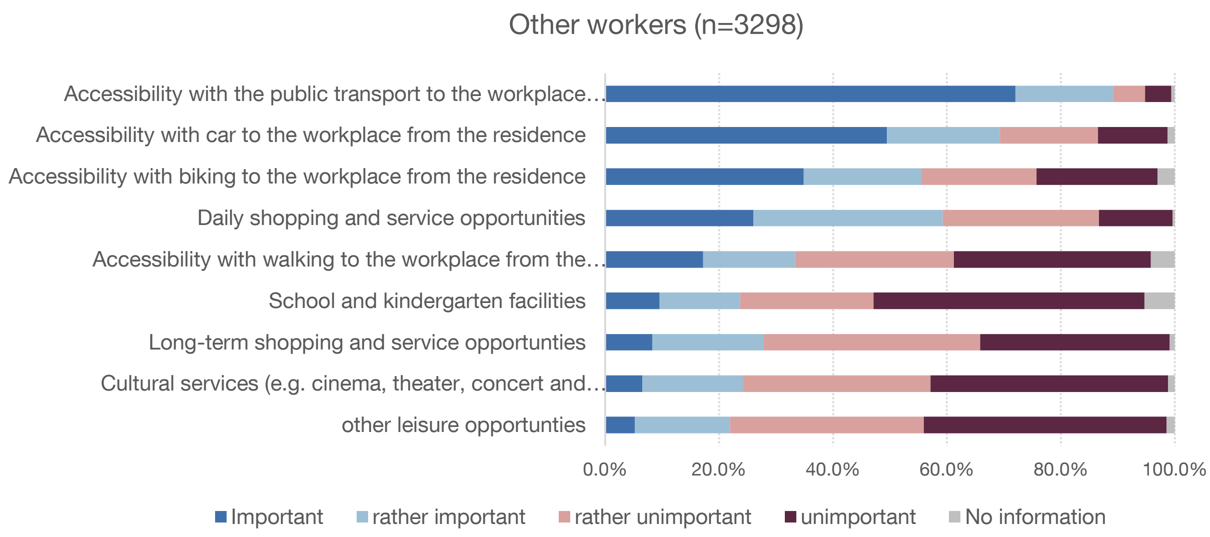


Figure 70. Importance assessment of certain attributes for workplace among other workers.

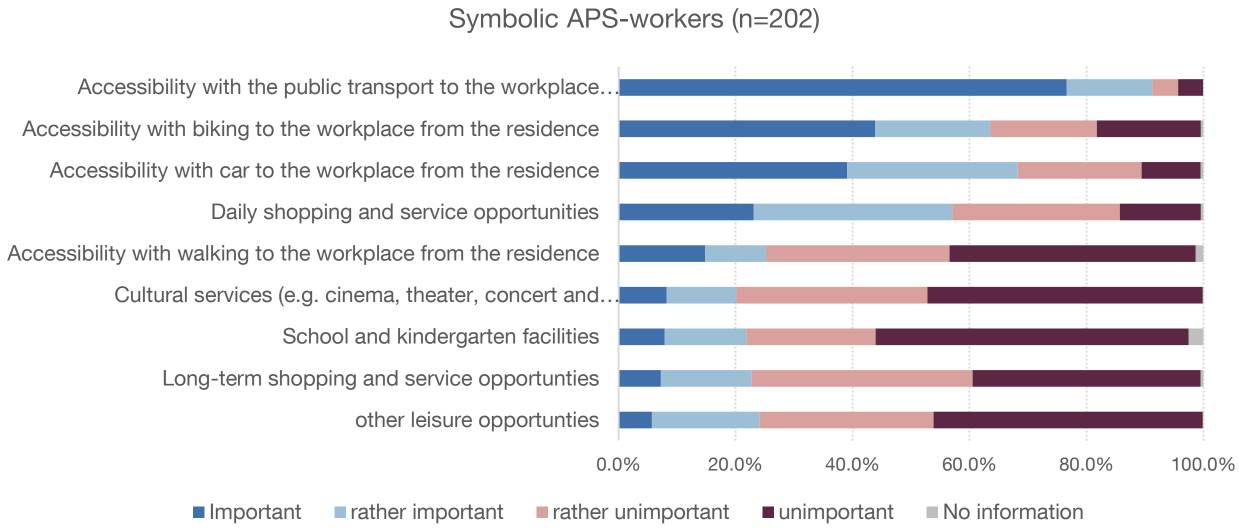


Figure 71. Importance assessment of certain attributes for workplace among symbolic APS-workers.

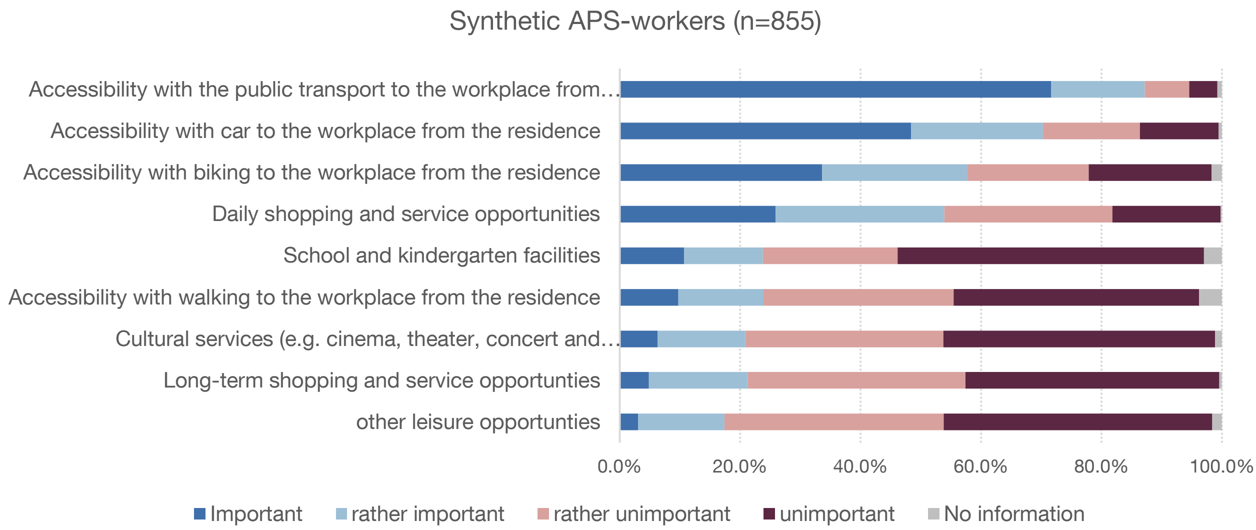


Figure 72. Importance assessment of certain attributes for workplace among synthetic APS-workers.

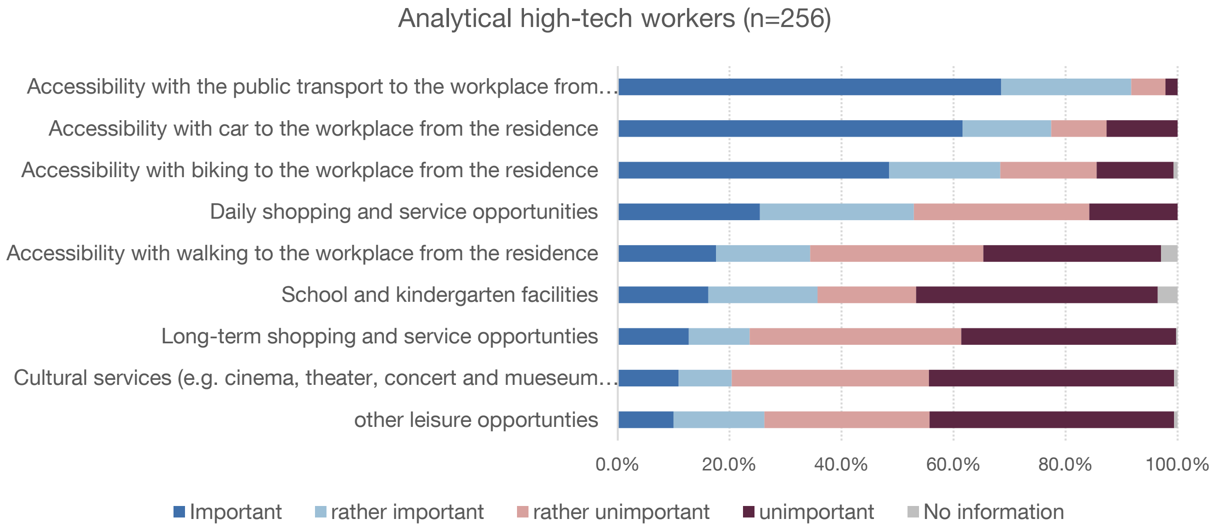


Figure 73. Importance assessment of certain attributes for workplace among analytical high-tech workers.

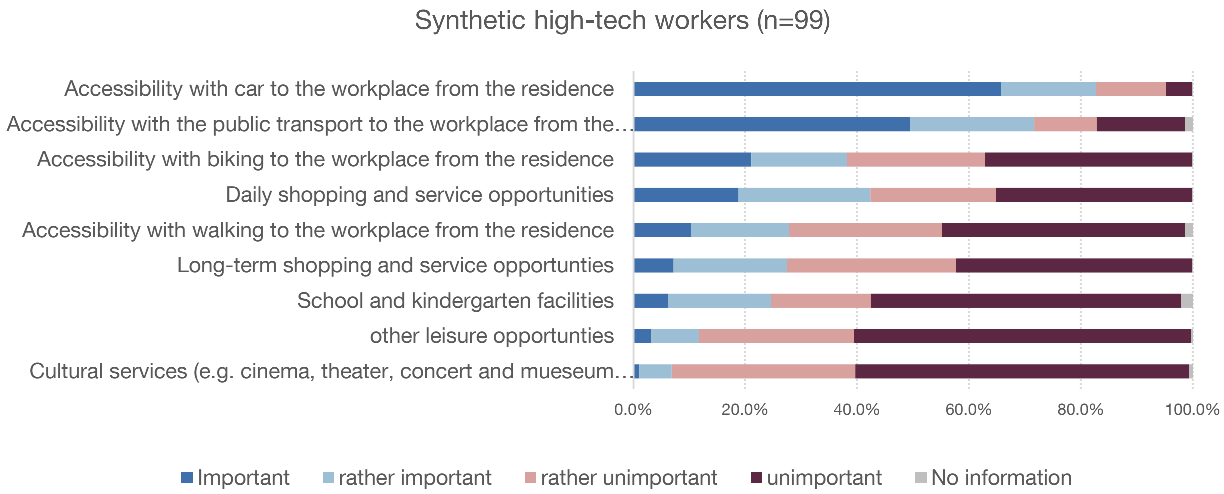


Figure 74. Importance assessment of certain attributes for workplace among synthetic high-tech workers.

7.1.3 Frequency and spatial pattern of leisure activities

Knowledge workers are also leisure consumers

Knowledge workers not only play the role of household member and employee, they are also leisure consumers (Frenkel, Bendit and Kaplan 2013a: 152). Moreover, as reported in the previous sections, the availability of cultural and leisure services are frequently assessed as an important factor in making residential choice. Hence, in order to better understand spatial behaviors in terms of residence and commute, analyzing the patterns of leisure behaviors also offers helpful information. Leisure activities refer to activities respondents participate in their spare time apart from working. This empirical work focuses specifically on cultural (e.g. museums, concerts, theaters and cinemas) and gastronomic facilities, and other leisure activities (e.g. sports). Activity patterns include the frequency of participation as well as the corresponding travel mode to reach the destination (a proxy of geographical distance of these activity destinations to either workplace or residence) across the daily, weekly or monthly trajectory.

Types and frequency of leisure activities

Among all groups of workers, the highest frequency in participating in cultural activities is one to three times per month, whereas the common frequency for other leisure activities is one to three times per week (Figures 75-76). When focusing on the share of population who visit cultural facilities frequently (one to three times per week) (Figure 75), it is observed that the share is larger at almost 30% among symbolic and synthetic APS-workers, whereas it is less than 10% among synthetic high-tech workers and 20% among analytical high-tech workers. Regarding the share of individuals who participate in other leisure activities one to three times per week (Figure 76), there is no apparent difference among these subgroups of workers. Symbolic APS-workers and analytical high-tech workers have a slightly larger share than other groups of workers. To summarize, symbolic APS-workers and synthetic APS-workers are relatively more active in participating in culturally related activities than synthetic high-tech workers.

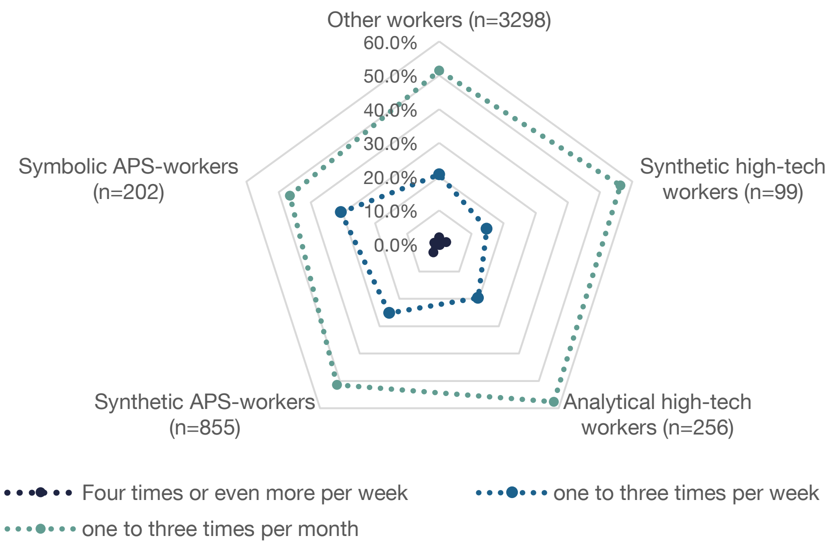


Figure 75. Frequency of visiting cultural and gastronomic services among each group of workers.

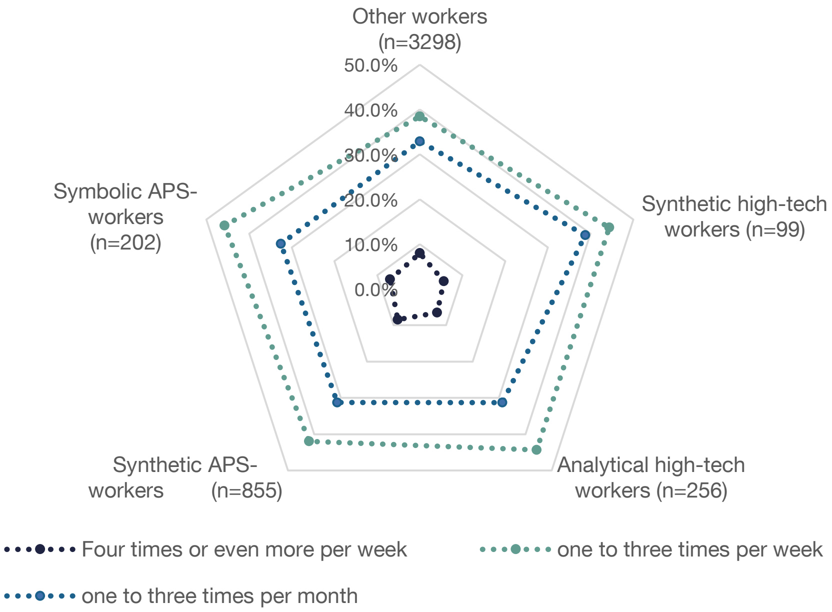


Figure 76. Frequency of visiting other leisure services among each group of workers.

Approximation of spatial proximity of leisure activities via travel modes

The web-survey does not include information on the spatial distribution of cultural and leisure activities that individuals actually visit. However, the travel mode could be used as a proxy for the geographical closeness across the space. The implicit assumption is that travel mode choice to some extent indirectly indicates the spatial closeness. Certain modes, e.g. cars or active modes, have a specific range of feasible travel distance: for instance, usage of car usually has a lower threshold of distance as feasible range, whereas cycling or walking in most cases have an upper limit of distance. In other words, the average length of trips conducted by car are longer than journeys walking or cycling. The results are mainly based on the comparison between the share of using cars and active modes.

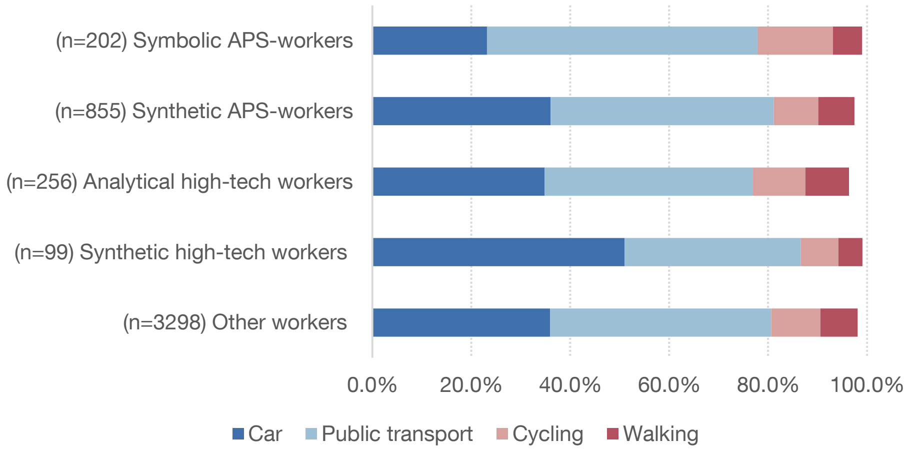


Figure 77. Travel mode split to participate cultural and gastronomic activities.

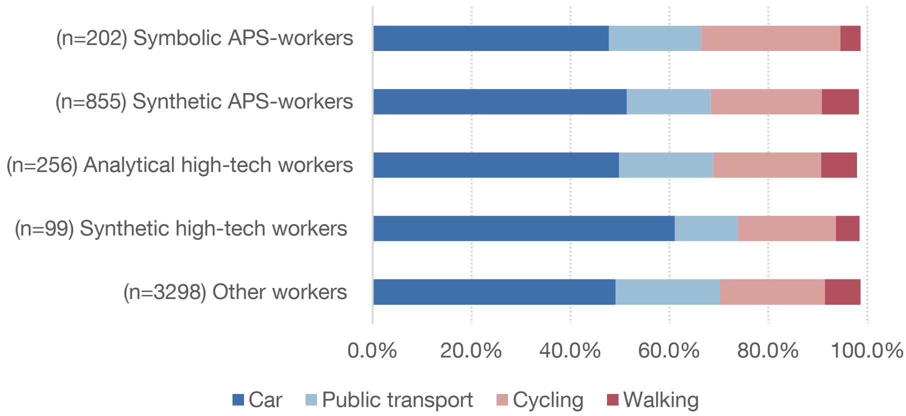


Figure 78. Travel mode split to participate other leisure activities.

Half of synthetic high-tech workers use cars to participate in cultural activities, whereas only 22% of symbolic APS-workers depend on cars as the travel mode to reach cultural activities (Figure 77). In addition, more than 20% of symbolic APS-workers also ride bikes to participate in their cultural activities, which are supposed to be located closer to their residences. The share of travel mode to other leisure activities does not vary much among different groups of workers (Figure 78). In summary, the geographical distribution of cultural and gastronomic facilities are closer and denser around the residence or workplace among symbolic APS-workers compared to synthetic high-tech workers.

7.2 Spatial attributes of current residence: evidenced willingness to pay

Section 7.1 introduces the importance assessment of each spatial attribute among each group of workers. It is also necessary to check whether these stated preferences are realized in actual choices or not. This section continues by analyzing the actual attributes of current residences, representing respondents' evidenced willingness to pay.

7.2.1 Residential cost, available services, and commute

Cost categories and number of services

The monthly residential rental cost per square meter has been classified into six categories: 0-5 Euros, 6-10 Euros, 11-15 Euros, 16-20 Euros, 21-25 Euros, and greater than 25 Euros. The number of long-term shopping and services, cultural and gastronomic services, as well as other leisure services within 1500m (500m is applied for daily shopping and services) from each current residential location are respectively calculated. Next, the average number of each type of service within each residential cost category is summarized. According to Figure 79, there is a steady increase in the average number of services from the lowest to the highest cost categories. This is easily understood, since the service provision are internally capitalized into the land value of the subsequent total cost of the residence. Worth noting is that from the cost category of 11-15 Euros to 16-20 Euros per month per square meter, there is a sharp increase in the number of services, which corresponds to the average rent (11-15 Euros) of all residences of the total samples in the region. Whether one is willing to pay a higher rent (above the median level) or not will be directly associated with the number of services available in the nearby areas.

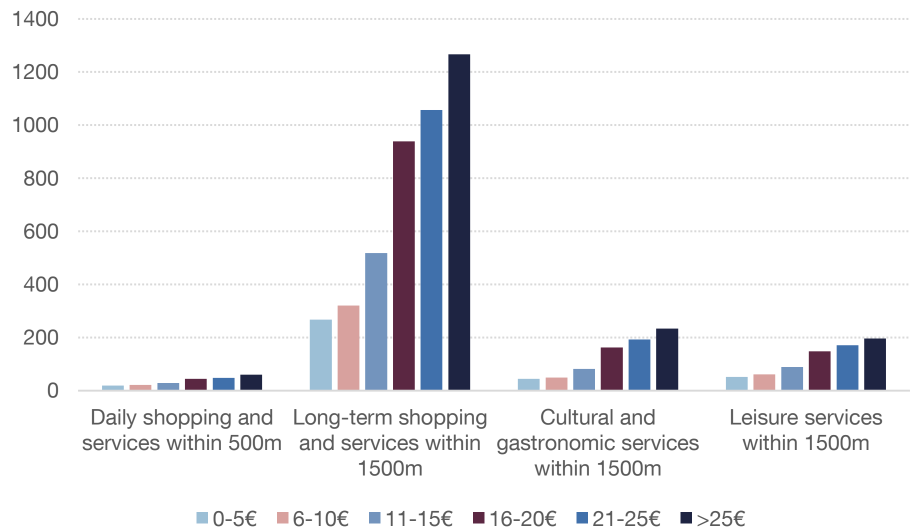


Figure 79. Residential monthly cost categories per square meter and the corresponding number of services (Author's own illustration; n=4710).

Cost categories and commute distance and time

Additionally, the average commute distance and time within each residential cost category is also calculated (Figure 80). With the increase of the residential unit cost, the commute distance gradually reduces. This trend slows down; when the average cost is above 15 Euros per square meter (average commute distance is below 15km). This is consistent with the commute tolerance theory that individuals are generally more willing to pay more to shorten the commute distance when facing a long commute (longer than 15km). Nevertheless, individuals will not continue to reduce the commute distance once the commute distance approaches 15km. Compared to commute distance, commute time does not have the same change trend with the increase in residential cost. The commute time in general shows a decreasing trend but there is a slight increase at the last cost category. To summarize, it is clearly shown that the demand for more shopping, leisure and cultural services near the residence or within short commutes corresponds to spending more money on the residential costs.

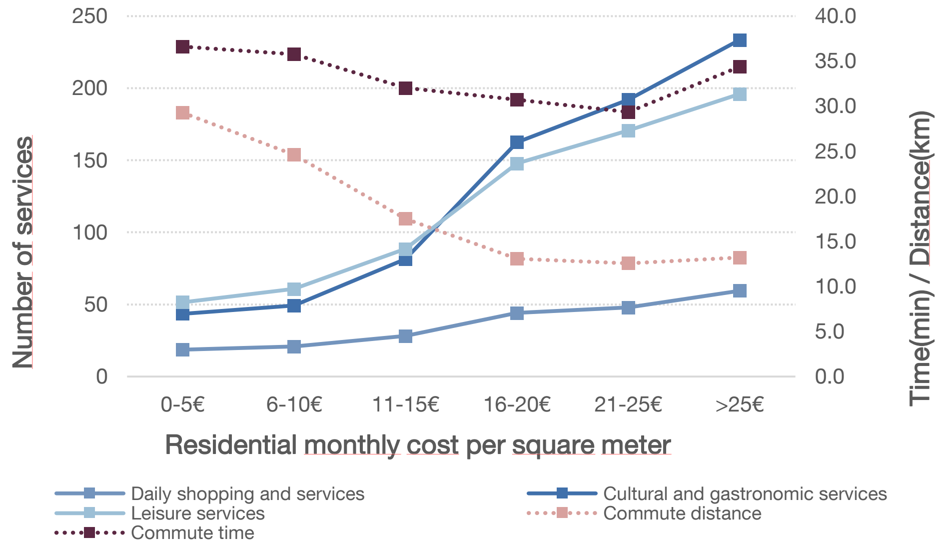


Figure 80. Residential monthly cost categories per square meter and the corresponding number of services and commute time and distance (Author's own illustration; n=4710).

7.2.2 Commute, dwelling size and residential unit cost

Mean commute distance and residential unit cost among each group of workers

This section continues to outline the typical behavioral characteristics of each group of knowledge workers. The median value of the rental cost and commute distance among each group of workers is calculated respectively (Figure 81). The average residential rental cost per square meter among synthetic high-tech workers is lowest at 11.9 Euros per square meter (sqm), and highest at 13.2 Euros per sqm among symbolic APS-workers. The average residential rental cost among synthetic APS-workers and analytical high-tech workers is 12.2 Euros per sqm and other workers pay 10.3 Euros per sqm. Correspondingly, the one-way commute distance of symbolic APS-workers is the shortest (8.0km), whereas it is longest (16.1km) among synthetic high-tech workers.

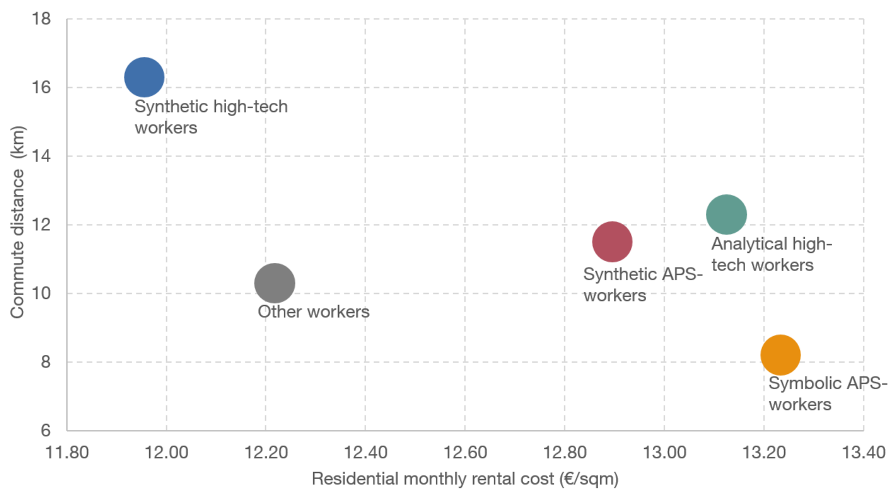


Figure 81. The average residential monthly cost per square meter and the commute distance among each group of knowledge workers.

Residential location choice usually faces a trade-off between access and space. As shown in the previous section, residential rental cost per square meter to some extent represents the value of unit space in a certain location, which is a monetary value of the overall accessibility to services and workplace of that location. Dwelling size represents the demand for space. This section will compare the housing size and the current rental cost per square meter among different groups of workers.

Distribution of dwelling size among each group of workers

According to Figure 82, dwellings with a size of 125m^2 claim the largest share (more than 30%) among synthetic high-tech workers, whereas dwellings with a size of 70m^2 are most common (27.5%) among symbolic APS-workers. The share of those living in dwellings with a size of 50 m^2 or 70 m^2 is relatively larger among other workers and symbolic APS-workers compared to synthetic high-tech workers. However, the share of individuals living in dwellings with an extremely large size of 175m^2 is largest among synthetic APS-workers. Interestingly, analytical high-tech workers are divided into two major categories, the share of individuals who live in a space of 70m^2 is almost same as for individuals occupying 125m^2. The share of small dwellings (50 m^2 and 70 m^2) is same with the share among symbolic APS-workers, which contradicts the second hypothesis.

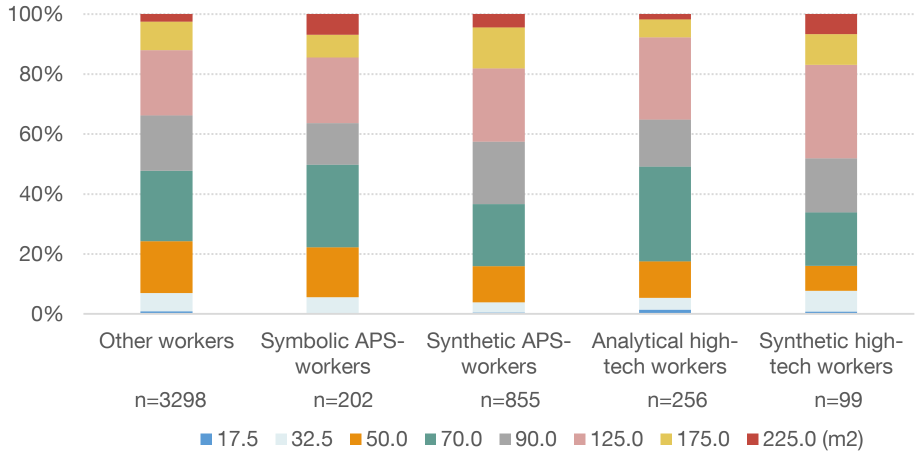


Figure 82. Distribution of the dwelling size among each group.

Distribution of residential unit cost among each group of workers

As shown in Figure 83, the distribution of the unit cost per sqm among each group of workers is compared. 16-20 Euros per sqm is the largest share of the rental categories and 11-15 Euros per sqm is the second largest share among symbolic APS-workers. Among synthetic APS-workers, the largest share of the average cost is 11-15 Euros per sqm and 30% of them are even willing to pay more than 16 Euros per sqm. In contrast, the first and second largest share of the residential unit cost that synthetic high-tech workers are willing to pay for is 11-15 Euros and 6-10 Euros per sqm. The largest share of analytical high-tech workers unit rental cost paid is less than 10 Euros per sqm. The results of their evidenced willingness to pay for residential location are consistent with the previous finding that symbolic APS-workers are more willing to pay for a location with better accessibility compared to synthetic high-tech workers. Synthetic APS-workers' evidenced willingness to pay is similar to symbolic APS-workers, whereas analytical high-tech workers are closer to synthetic high-tech workers. Unexpectedly, 22.1% of synthetic high-tech workers pay more than 20 Euros per square meter monthly for their residence.

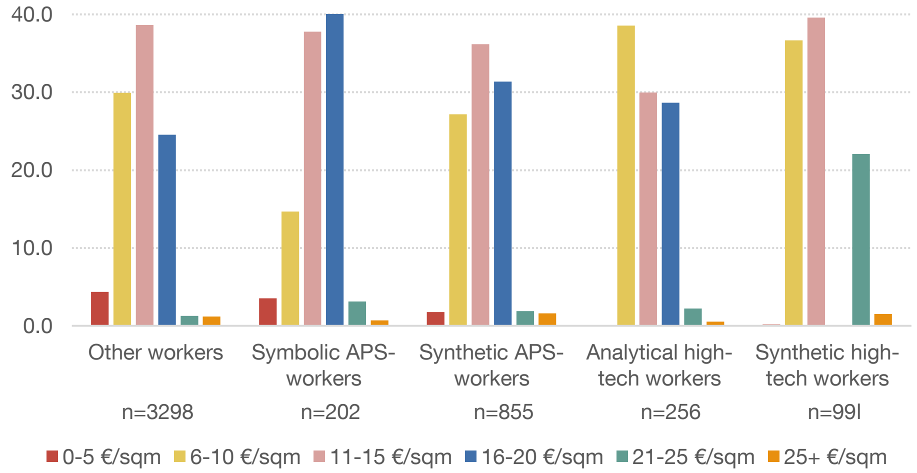
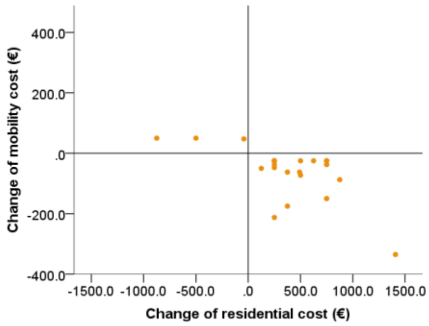


Figure 83. Distribution of residential monthly cost per square meter among each group

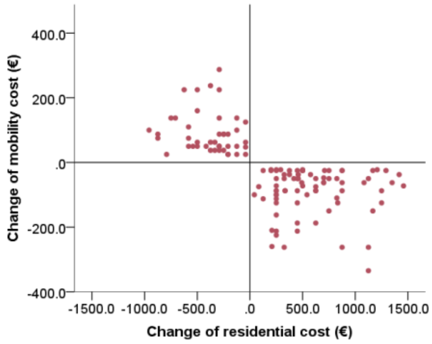
7.2.3 Cost allocation among residence, mobility, and services

Cost allocation among residence and mobility

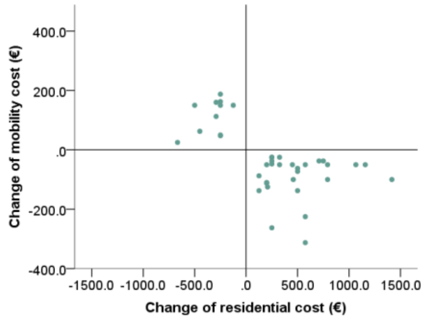
Following the comparison of distribution of dwelling size and unit cost in section 7.2.3, another way to study the access-space trade-off is by examining the cost allocation between total spent on residence and mobility, since mobility costs are highly related to accessibility. Because information on mobility costs is only available for the previous and current situation rather than the search process, the comparison focuses on the previous and current situation. In addition, the analysis specifically focuses on individuals' compromise between change of residential costs and change of mobility costs: either individuals who increase residential costs and decrease mobility costs, or individuals who decrease the costs spent on residence and raise their outlay on mobility. As shown in Figure 84, most symbolic APS-workers tend to sacrifice their residential costs for reduced mobility costs (namely better accessibility) than the other way round. In contrast, there is no result showing that synthetic high-tech workers' have a greater tendency to save residential costs by compensating with a larger mobility costs compared to the opposite case. This is to some extent expected, since the decreased residential unit cost is very probably offset by the increased dwelling size in total residential costs. Other workers are similar to symbolic APS-workers, but to a lesser degree regarding the differentiation between two contrasting trade-offs. The cost allocation between residence and mobility among analytical high-tech workers is more similar to synthetic high-tech workers, whereas synthetic APS-workers are more similar to symbolic APS-workers.



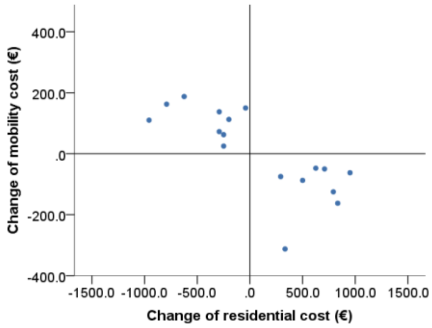
(Symbolic APS-workers; n=23)



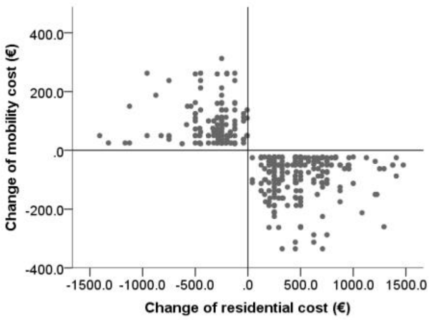
(Synthetic APS-workers; n=129)



(Analytical high-tech workers; n=41)



(Synthetic high-tech workers; n=18)

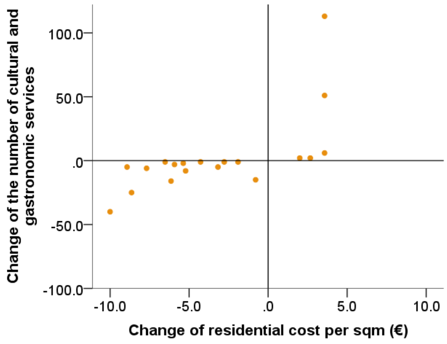


(Other workers; n=425)

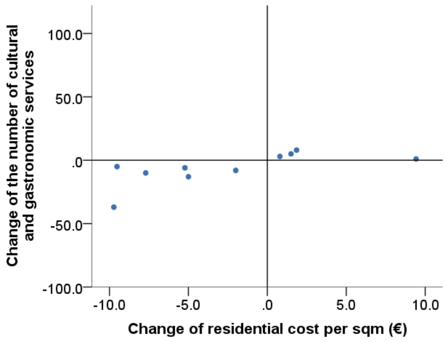
Figure 84. Trade-offs between residenial costs and mobiltiy costs after moving among each group.

Cost allocation between services and residential cost

Since symbolic APS-workers frequently mentioned the importance of the availability of cultural and gastronomic services, and the attractiveness of the locality, this section continues by examining whether they are indeed willing to pay additional costs for a larger number of services. The differentiation between symbolic APS-workers and synthetic high-tech workers is scrutinized first, since they have distinct assessments of importance regarding these services. Unexpectedly, Figure 85 does not show apparent differences regarding the willingness to pay for additional services between symbolic APS-workers and synthetic high-tech workers.



(n=19)



(n=10)

Figure 85. Trade-offs between residential costs and gastronomic services after moving among symbolic APS-workers (left) and synthetic high-tech workers (right).

7.3 Underlying trade-offs between 'space', 'access', and costs in residential choice

Previous separate analyses on the residential cost category, the service level, commute situation, as well as the dwelling size do not give much information on the direct trade-off process between these aspects. Hence, this section continues to track the simultaneous pairwise consideration of residential attributes. Since trade-off is frequently associated with the largest sacrifice one has to make for the decision, it makes more sense to focus on the key aspects of residential choice: namely the space of the dwelling and the accessibility of the residence. Accordingly, the characteristics of the current residence are compared with the unselected alternative residence, given the precondition that the total expenditure on the current residence is either larger than or at least equal to that of the alternative residence.

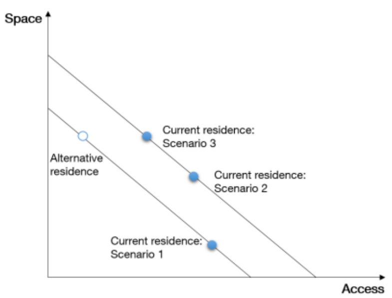


Figure 86. Preference for the accessibility over dwelling size.

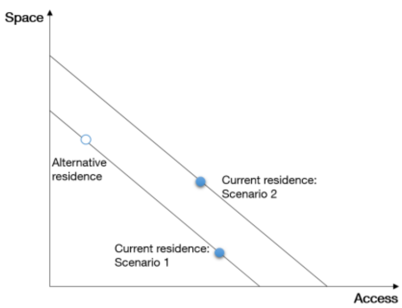


Figure 87. Strong preference for the accessibility over dwelling size.

This part will begin by introducing the trade-off process. It is apparent that individuals have a larger preference for the accessibility of a residence over the space in the following three scenarios. Firstly, individuals keep the residential costs constant and sacrifice the dwelling size for access (Scenario 1 in Figure 86). Secondly, individuals spend more on residential costs where access has been improved and size has been reduced (Scenario 2 in Figure 86). Thirdly, individuals accept increased residential costs and improve access, while keeping the dwelling size constant (Scenario 3 in Figure 86). Individuals making choices on the terms in these three scenarios are termed individuals with preference for access over space (Figure 86). People trade off either the dwelling size or residential costs for better accessibility. If the third scenario is excluded, individuals whose choices are in the first and second scenarios are actually sacrificing space for better access. These individuals are defined as individuals with a strong preference for access over the space (Figure 87). The space is represented by the dwelling size. Access to a residence is represented using various indicators: firstly the commute distance and time, secondly the total number of services within a given distance, and lastly the residential monthly cost per square meter (Section 7.2.1 explains why it is a reasonable proxy for the overall accessibility of one location).

7.3.1 Trade-offs between commute length/duration and dwelling size

All socio-demographic profiles

As shown in Figures 88-89, the share of symbolic and synthetic APS-workers who decrease the commute time or distance when size was constant or decreases (preference for shorter commute over dwelling size or costs) is larger than that of synthetic high-tech and analytical high-tech workers. That is, the willingness to pay more for spatial or temporal proximity to the workplace than the dwelling size is larger among workers in APS sectors than high-tech industries. This somehow indirectly supports the second hypothesis that synthetic APS-workers are willing to trade off costs for short commutes. Keeping the size constant and simultaneously increasing the accessibility to the workplace will require synthetic APS-workers to spend more on the residential costs in the new residence. However, when focusing on those with a strong preference for job accessibility over dwelling size, a larger share of synthetic high-tech workers display a strong preference for shorter commute time over dwelling size compared to all other groups of workers, but the differentiation is relatively small.

As expected, only a very small share of individuals show a strong preference for job accessibility over the dwelling size. This corresponds to their reasons for moving related to inadequate size; very few individuals (less than 5%) sacrificed size for better job accessibility in residential relocation, since the dwelling size is a less elastic demand compared to the short commute and the total expenditure for the residence.

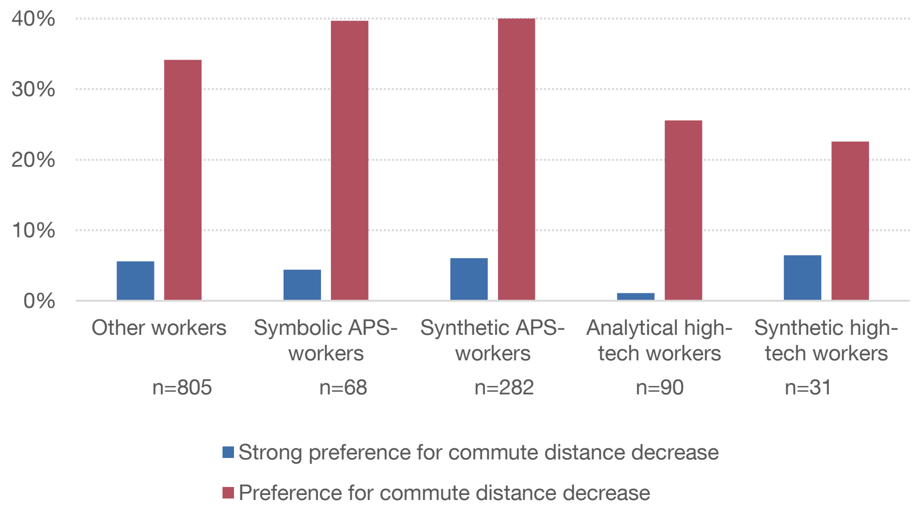


Figure 88. Share of individuals with (strong) preference for short commute distance over dwelling size.

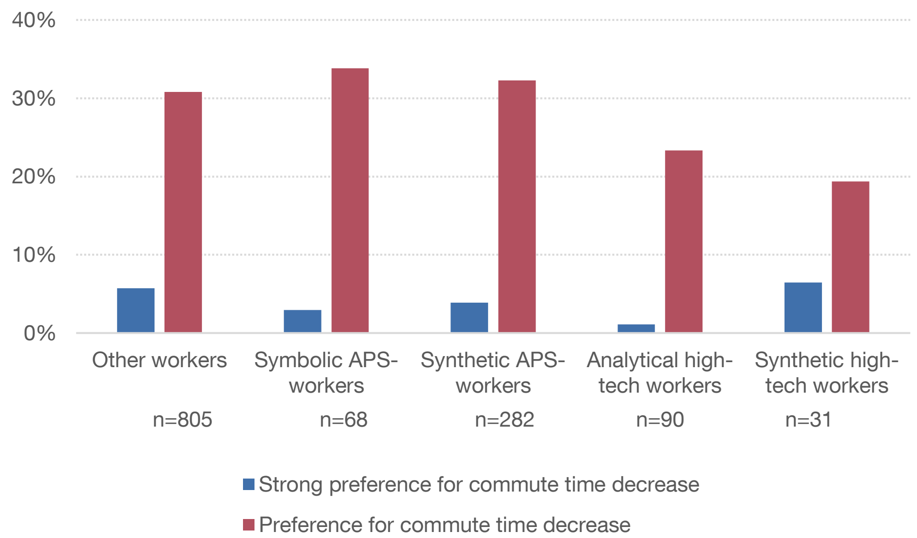


Figure 89. Share of individuals with (strong) preference for short commute time over dwelling size.

Specifically focusing on single-person or medium-income households

Regarding the share of individuals showing a strong preference for commute over dwelling size is relatively small, the analysis controlling for income and household size focuses only on individual workers who show preference for shorter commute time or distance over dwelling size. Unexpectedly, when focusing only on certain demographic profiles such as single-person households, results are inconsistent with the previous findings (Figures 90-91). Results do not show a larger preference for spatial proximity among symbolic APS-workers than synthetic high-tech workers do. This to some extent contradicts the second hypothesis that synthetic high-tech workers have a larger preference for dwelling size than other workers. When focusing on households with medium income level, the difference between symbolic APS-workers and synthetic high-tech workers still exists, but to a much less degree.

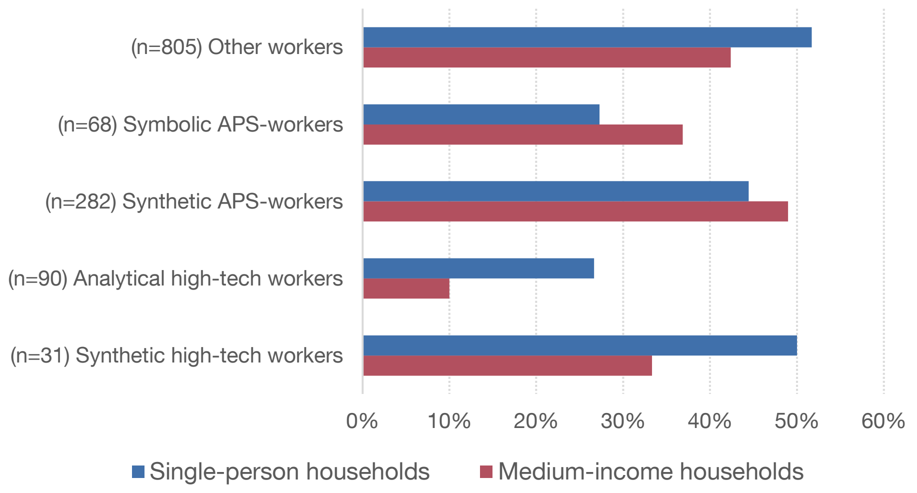


Figure 90. Share of individuals with a preference for short commute distance over dwelling size among single-person and medium-income households.

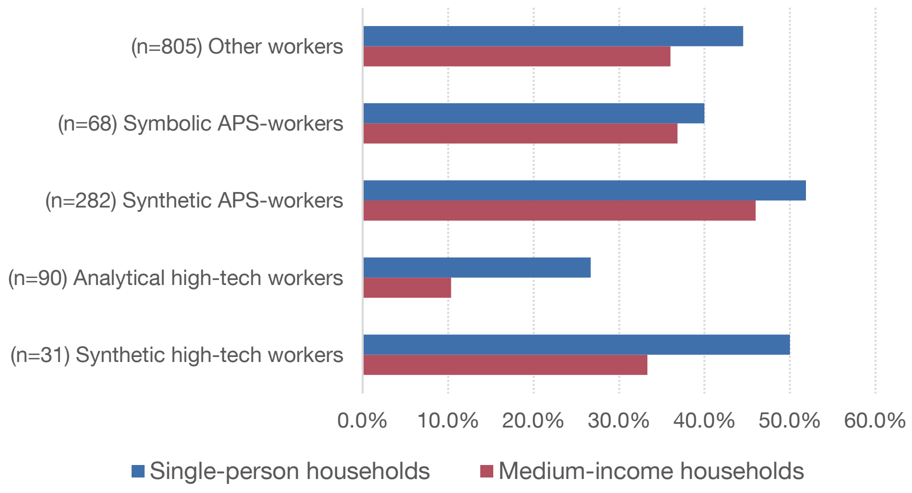


Figure 91. Share of individuals with a preference for short commute time over dwelling size among single-person and medium-income households.

7.3.2 Trade-offs between services and dwelling size

Here public transport stations are also included together with shopping, cultural and leisure services in the analysis. The revealed preference for services is identified when at least one aspect of a service is improved by comparing the current residence with the (denied) alternative residence.

All socio-demographic profiles

More than 60% of symbolic APS-workers show a larger preference for at least one type of service (daily shopping, leisure and cultural, gastronomic services, or public transport) than the dwelling size (Figure 92). Analytical high-tech workers and synthetic APS-workers' revealed preferences are more similar to symbolic APS-workers. In contrast, the share of individuals with preference for services over the dwelling size or residential cost is only 40% among synthetic high-tech workers. Other workers lie in between these two contrasting groups. Similar to the finding in 7.3.1, there is still no apparent differentiation of the strong preference for services over dwelling size among each group of workers.

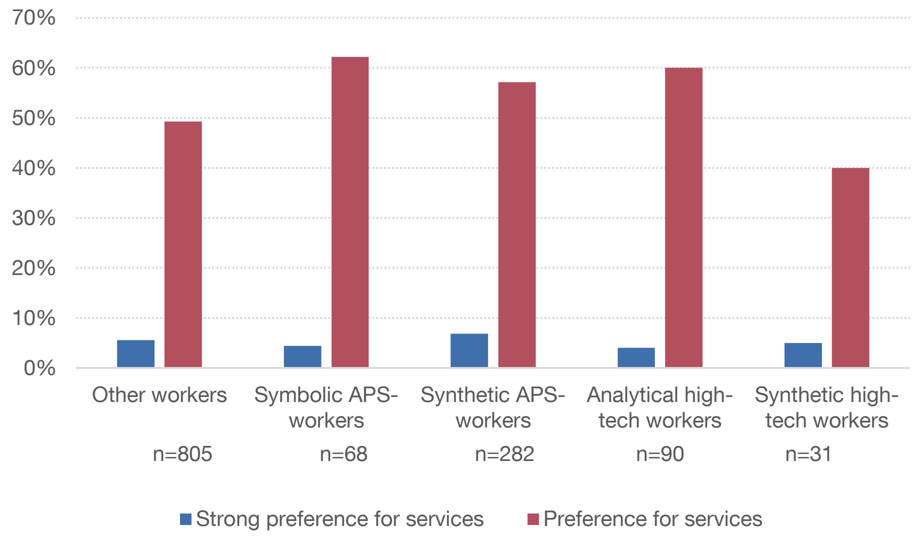


Figure 92. Share of individuals with a (strong) preference for services over dwelling size.

Specifically focusing on single-person or medium-income households

As shown in Figure 93, symbolic APS-workers in single-person households display the greatest preference for services over the dwelling size or residential cost among all groups of workers. In contrast, only 30% of synthetic high-tech workers choose a residence with a better service level compared to the alternative residence. The contrast between these two groups of knowledge workers still exists after controlling for household size, which confirms the first and the second hypothesis that synthetic APS-workers tend to pay more for central residential locations with adequate services than the dwelling size. When the household income is controlled for under the medium level, the differences in preference for certain services are no longer that apparent. Nevertheless, there are still more synthetic APS-workers (57.7%) indicating their preference for services over dwelling size compared to analytical high-tech workers (47.1%).

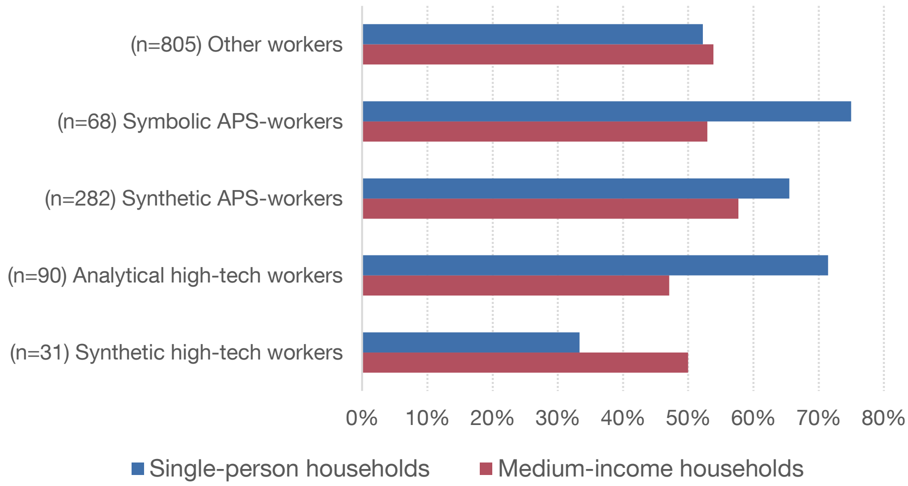


Figure 93. Share of individuals with a preference for services over dwelling size among single-person and medium-income households.

7.3.3 Trade-offs between 'overall accessibility' and dwelling size

All socio-demographic profiles

Unit cost is used as a proxy for the overall accessibility of the location. According to Figure 94, more than one fourth of symbolic APS-workers and synthetic APS-workers show a larger preference for overall accessibility over the dwelling size, whereas the share is only 20% among synthetic high-tech workers. However, analytical high-tech workers display a surprisingly higher share of individuals with a preference for overall accessibility over dwelling size, which contracts the second hypothesis. It appears that individuals may increase the residential unit cost and decrease the size at the same time. It is revealed that nearly 10% of synthetic APS-workers show a larger preference for accessibility than dwelling size. In contrast, the share is only 5% among synthetic high-tech workers.

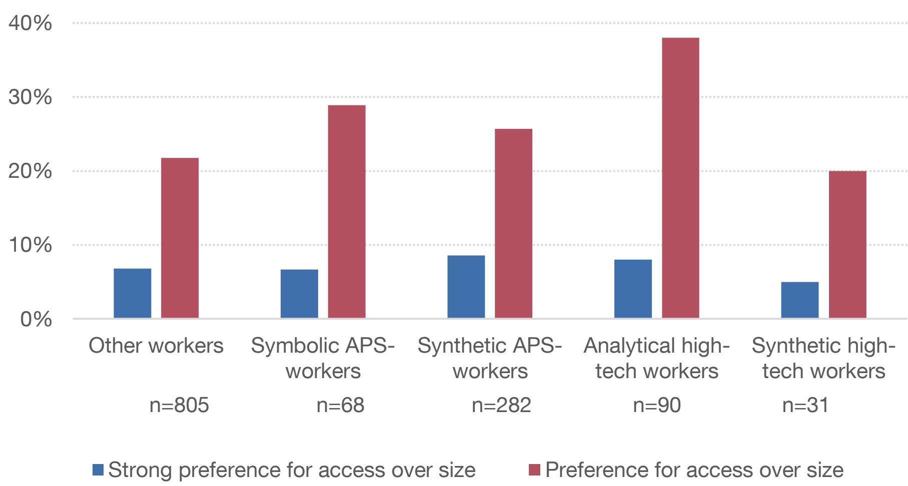


Figure 94. Share of individuals with a (strong) preference for overall accessibility over dwelling size.

Specifically focusing on single-person or medium-income households

If the analysis focuses only on single-person households (Figure 95), it is revealed that an even a larger share of synthetic high-tech workers display a preference for the overall location over the dwelling size than symbolic APS-workers. The results after controlling for income level do not confirm the assumption that synthetic APS-workers have a greater preference for overall accessibility compared to synthetic high-tech workers.

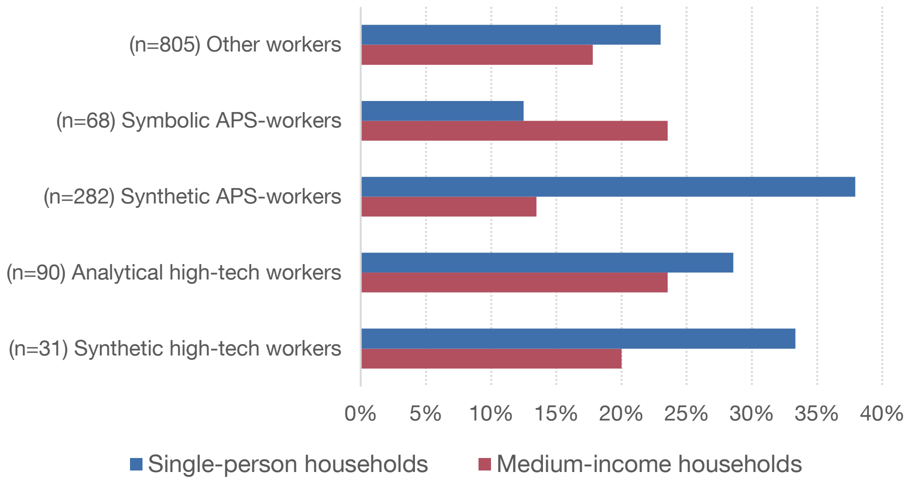


Figure 95. Share of individuals with a preference for overall accessibility over dwelling size among single-person and medium-income household.

7.4 Revealed preference for each attribute in residential choice

As mentioned in Chapter 2, individual decision-makers take into account many factors simultaneously in their residential choice. Factors for consideration include micro-scale factors such as dwelling size, dwelling cost and housing ownership. In addition, individuals also consider the meso-scale neighborhood attributes such as the availability of certain services and the attractiveness of the locality. Last but not least, job accessibility in terms of the commute time and distance also impacts their decision-making. Following the pairwise trade-off analysis in the previous section, an overall analysis of the preference for each aspect is here conducted. The percentage of individuals improving certain attributes is used as an approximate estimation of the relative importance of that attribute. Residential attributes are grouped into three categories: dwelling-related , neighborhood-related attributes and job accessibility.

7.4.1 Compare current residence with previous residence

Preference for dwelling-related attributes

As shown in Figure 96, more than half of individuals have a larger dwelling size compared to their previous situation. When comparing the different shares of individuals improving certain attributes at the current residence compared to previous residence among each group of workers, it is revealed that more symbolic and synthetic APS-workers improve the dwelling size and housing ownership after the residential move. In contrast, more synthetic high-tech workers reduce their residential costs after moving to the current residence.

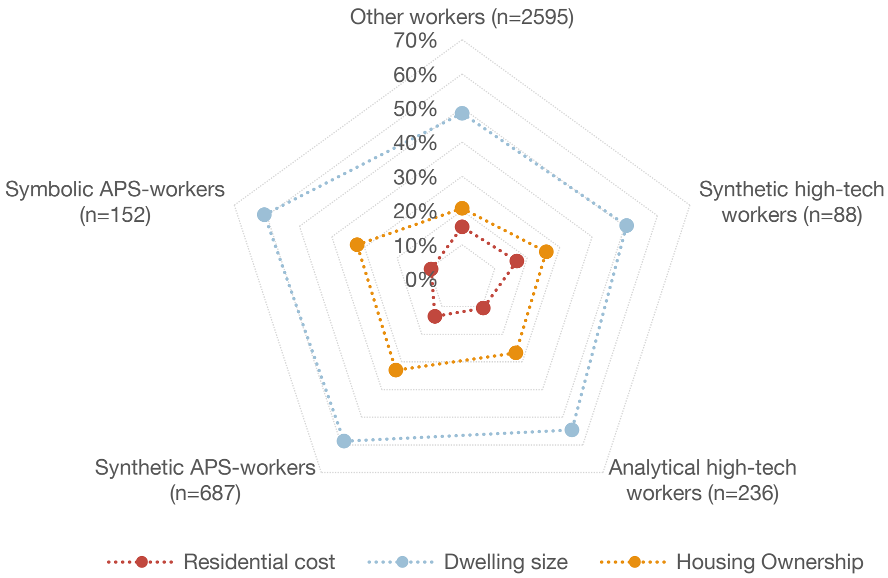


Figure 96. Shares of individuals improving dwelling-related attributes by comparing the current residence to the previous residence.

Preference for neighborhood-related attributes

Interestingly, a larger share of synthetic high-tech and analytical high-tech workers' current residences have better accesses to shopping, cultural or leisure services compared to their previous residences, which contradicts the second hypothesis (Figure 97). However, the share of symbolic APS-workers who reduced the distance to public transport station after the residential move is larger than that of other groups of workers, which indirectly supports the second hypothesis. The share of synthetic high-tech workers improving access to schools is almost twice as high as the share of symbolic and synthetic APS-workers.

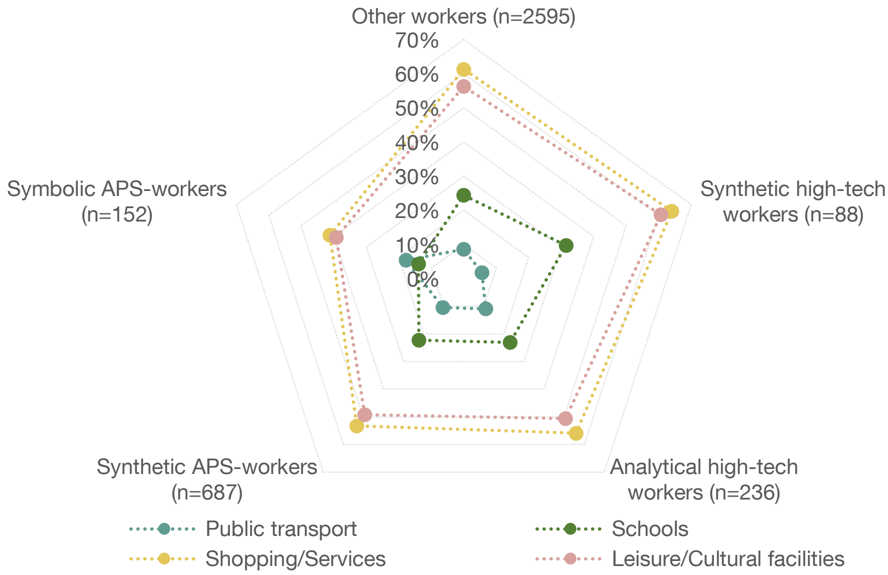


Figure 97. Shares of individuals with improvements of neighborhood-related attributes by comparing current residence to previous residence.

Preference for job accessibility

Interestingly, Figure 98 shows that the share of individuals who decrease the commute distance is almost same as the share of decreasing the commute time. There is only a slightly larger share of synthetic high-tech workers shortening the commute distance than symbolic APS-workers. However, there is nearly no clear differentiation between synthetic APS-workers and analytical high-tech workers.

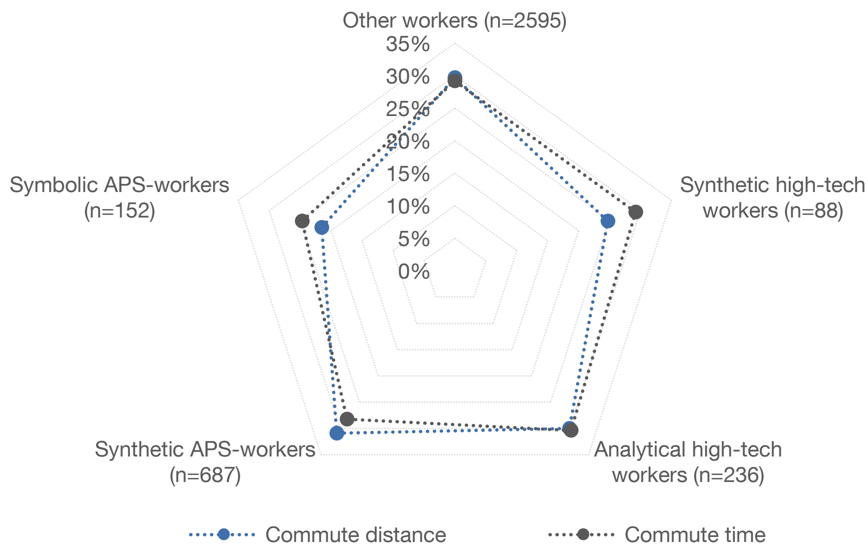


Figure 98. Shares of individuals with improvements of job-related attributes by comparing the current residence to previous residence.

Integration of all aspects

When comparing the absolute share of improvements across different attributes, the share of individuals increasing the dwelling size is the largest (approximately 40%) (Figure 99). This is as expected, since all groups frequently mention 'inappropriate dwelling size' as the important motivation for moving residence. Correspondingly, the share of individuals who reduce residential costs via moving is least, which is related to the offsetting impact of an increased dwelling size in some cases. In addition, individuals in most cases tend to spend more to upgrade their residences, once they devote effort and tolerate relocation costs.

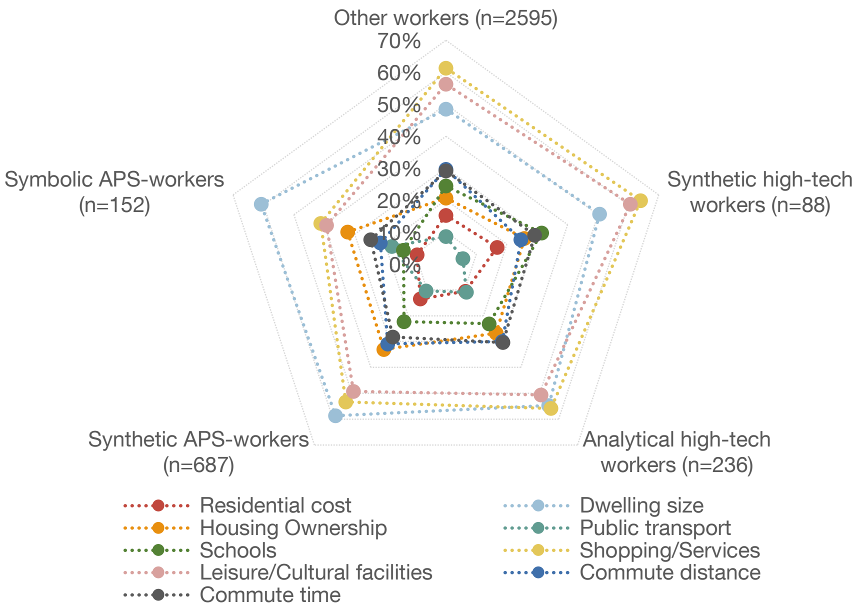


Figure 99. Shares of individuals with improvements of all attributes by comparing the current residence to the previous residence.

7.4.2 Compare current residence with alternative residence

Whereas motivations drive residential move, preferences influence the choice of current residence among alternatives

As expected, individuals generally tend to make more effort to improve attributes mentioned as the motivation for moving, which in most cases related to objective constraining factors. For instance, a household entering another life-cycle stage requires larger or smaller dwelling size. These life-cycle stage related attributes do not vary that much between different groups of workers. Nevertheless, when individuals choose a residence among several available alternatives, they will simultaneously consider many other dimensions ranging from 'neighborhood attractiveness' to 'accessible distance to public transport station', etc. Residential move thus represents a window of opportunity where individuals can both satisfy their basic needs such as the dwelling size and housing ownership, and simultaneously their secondary but important preferences such as the surrounding facilities and the attractiveness of the residential neighborhood. In this case, the current and alternative residence are compared with each other, since the selection of a residence among all alternatives is subject to the same decision-making system in terms of monetary and time constraint.

Preference for dwelling-related attributes

Not surprisingly, a large share (80%) of individuals among all groups of workers tend to choose the one with less residential costs among various available residential options (Figure 100). A larger share of synthetic high-tech workers choose the residence with larger dwelling size than other groups of knowledge workers, which confirms our second hypothesis. Due to their existing relatively larger share of housing ownership, the share of synthetic high-tech workers choosing to purchase the dwelling and deny the alternative with rented tenure is relatively smaller than other groups of workers.

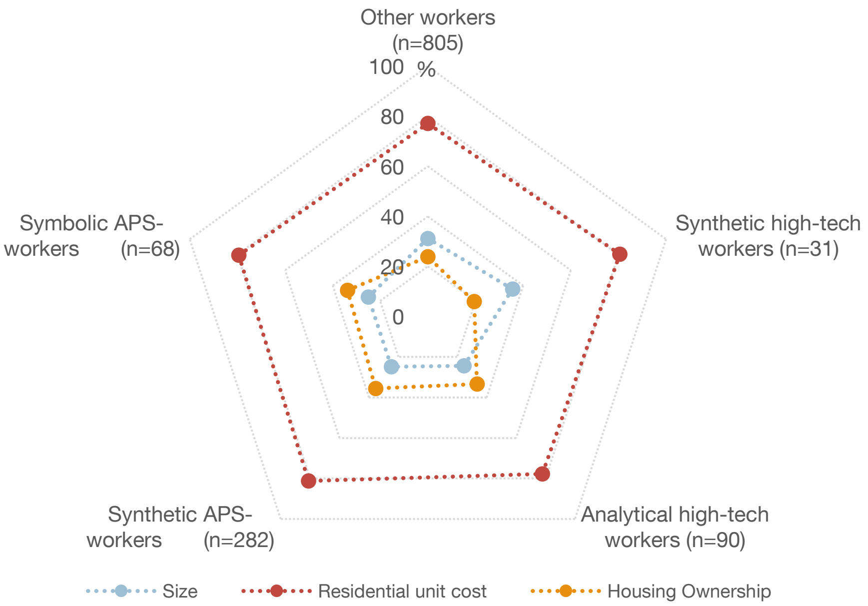


Figure 100. Shares of individuals with a preference for dwelling-related attributes by comparing the current residence to the alternative residence.

Preference for neighborhood-related attributes

Figure 101 shows that more symbolic and synthetic APS-workers tend to choose the residence with more leisure or cultural and shopping facilities than other groups. In addition, more synthetic APS-workers tend to choose the residence with a closer distance to public transport stations, which is closely related to the larger likelihood of their using public transport to commute (see chapter 8).

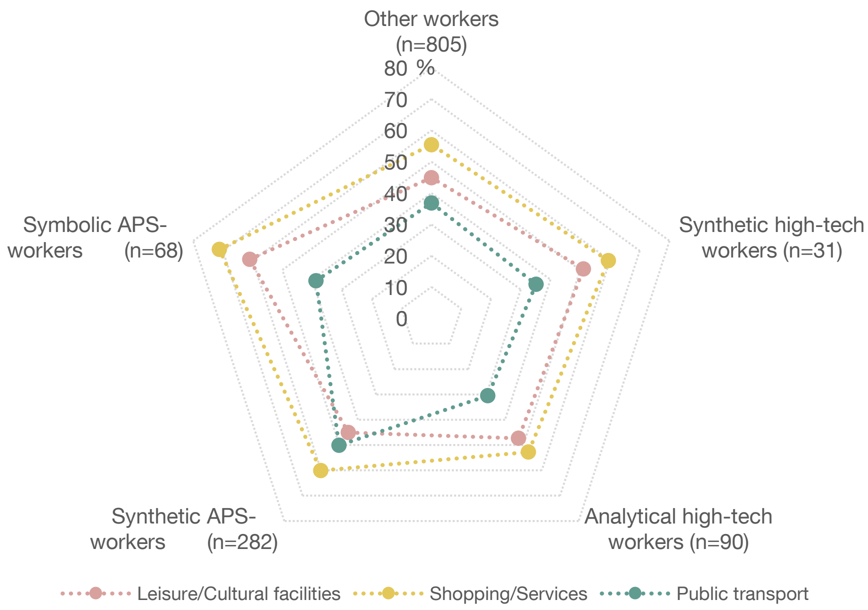


Figure 101. Shares of individuals with a preference for neighborhood-related attributes by comparing current and alternative residence.

Preference for cafés-bars-restaurants (Space offering interaction opportunities)

This section further refines the objects of the analysis specifically to cafés, restaurants, and bars, which are much more relevant for creating opportunities for interactions. Figure 102 shows that more than 30% of symbolic and synthetic APS-workers choose the residence with more services. This confirms the assumption that symbolic and synthetic APS-workers have a larger demand for public spaces facilitating frequent face-to-face interactions than synthetic and analytical high-tech workers.

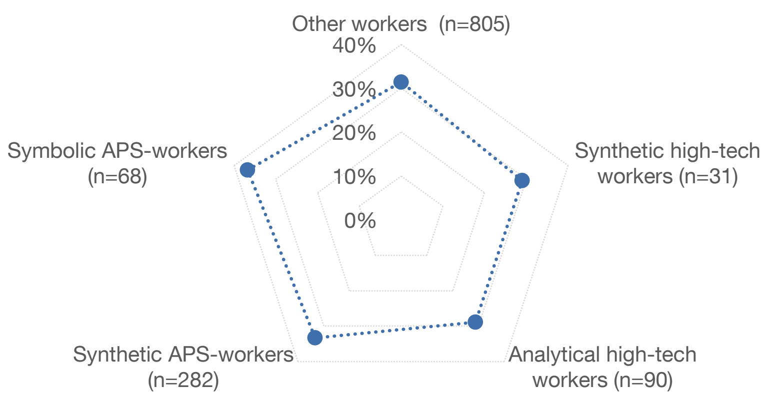


Figure 102. Shares of individuals with a preference for the services of cafés, bars and restaurants by comparing the current residence to the alternative residence.

Preference for job accessibility

Regarding job accessibility, more symbolic APS-workers and synthetic APS-workers tend to choose the residence with shorter commute distance, whereas more synthetic high-tech workers choose the residence with less commute time (Figure 103). The shorter commute time together with the long commute distance of synthetic high-tech workers is again related to their relatively frequent use of cars as the commute mode (see Chapter 8).

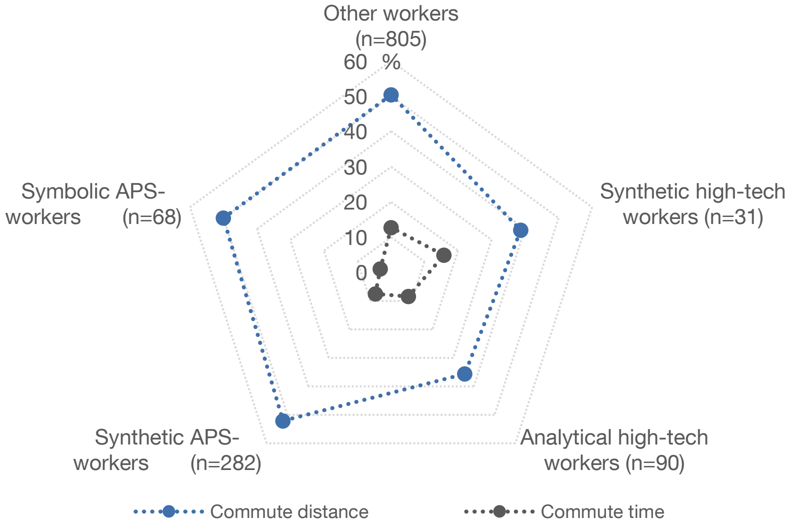


Figure 103. Shares of individuals with a preference for job accessibility by comparing the current residence to the alternative residence.

Integration of all aspects

If all attributes are summarized together (Figure 104), two main findings emerge: Firstly, residential cost remains the most important factor in residential choice, regardless of the group of workers. Secondly, the share of individuals who improve spatial attributes, such as the number of services nearby, is much larger than the share improving housing ownership and commute time.

Figure 104. Shares of individuals with a preference for all attributes by comparing the current residence to the alternative residence.

7.4.3 Compare the length of previous-alternative-current commute trip

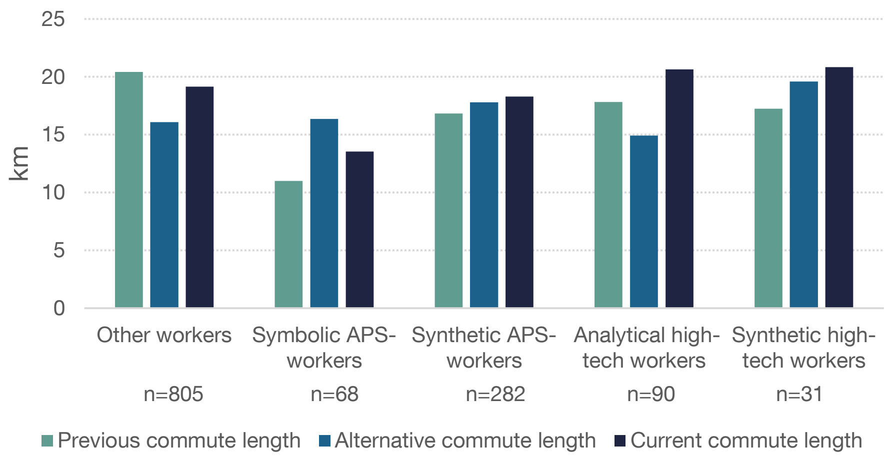


Figure 105. Comparison of previous, alternative and current commute length among each group of workers.

The average commute distance for each situation in terms of previous, alternative and current situation for each group of workers is calculated in Figure 105. Symbolic APS-workers opt for shorter commute distance in each situation compared to other groups of workers. Although symbolic APS-workers also viewed residences with longer commutes, they finally choose the residence with a shorter commute distance. Analytical high-tech workers also show some tendency to reduce the commute distance; nevertheless, they are finally more inclined to accept a larger commute distance. Synthetic high-tech workers decide relatively independent of their current job compared to the previous and alternative situation. Synthetic APS-workers opt for a relatively constant commute distance no matter what the previous, alternative or the current situation. There is only a slight increase in their commute distance from the previous to current situation. The commute distance of synthetic APS-workers is smaller than that of synthetic and analytical high-tech workers, but larger than symbolic APS-workers. Other workers also try to locate much closer to jobs, but they have to accept a residence with a relatively shorter commute distance.

7.5 Summary of key findings

- There is no apparent difference regarding motivations for moving among each group of workers and inappropriate size and demand of ownership are frequently mentioned. In contrast, there are differences between synthetic high-tech workers and synthetic APS-workers regarding the assessment of importance of certain residential attributes. Workers in APS sectors regard the attractiveness of the locality, the availability of cultural and gastronomic services, the accessibility of public transport, as well as walking- or cycling-friendly neighborhoods as important. In contrast, housing ownership, facilities and quality of the dwelling, noise and safety level of the neighborhoods are frequently regarded as important among synthetic high-tech workers.
- Symbolic APS-workers are relatively more active in participating cultural and other leisure facilities than synthetic high-tech workers. In addition, the share of using cars to reach leisure activity destinations is larger among synthetic high-tech workers than symbolic APS-workers, whereas the share of individuals cycling to participate in other leisure activities is smaller among symbolic APS-workers than that of synthetic high-tech workers.
- By integrating the dwelling size, commute distance and the average residential cost per square meter with these attributes, it is clearly revealed that larger dwelling size is always accompanied with lower residential unit cost and an averagely longer commute; similarly, a smaller dwelling size is coupled with a higher residential unit cost and averagely shorter commute. By analyzing the characteristics of the current residence, synthetic high-tech workers are more frequently willing to pay and choose the first bundle of attributes, whereas the second bundle of attributes attracts more symbolic APS-workers. In addition, costs are largely allocated in residence than mobility among symbolic APS-workers, whereas this is less apparent among synthetic high-tech workers. These results verify the space-access trade-off in the second hypothesis.
- Knowledge workers indeed show different preferences for shorter commutes or a larger number of services compared to a larger dwelling size. More symbolic and synthetic APS-workers display a preference for shorter commute and a larger number of services over the dwelling size, whereas the opposite is the case among analytical and synthetic high-tech workers. Nevertheless, when focusing on specific demographic profiles such as medium income or single-person households, the difference either disappears or even shows an opposite tendency.

- The comparison between current and alternative residence is consistent with the second hypothesis. Synthetic APS-workers prefer to choose a residence with shorter commutes, more services and especially bars, cafés and restaurants. In contrast, a relatively larger share of synthetic high-tech workers prefer to choose a residence with a larger dwelling size and longer commute. Half of symbolic and synthetic APS-workers choose residences with a shorter commute distance, whereas the share is only 40% among synthetic and analytical high-tech workers.

8 Knowledge workers use different commute transport modes

Choice of commute mode is closely related to both residential locations and the residential trade-offs between 'access and space' introduced in the previous two chapters. This chapter continues to examine the actual commute choices of knowledge workers. In addition, this chapter also compares the relative importance of structural variables and mobility preference on the choice of commute mode.

8.1 Travel modal split for commute trips

The analysis does not consider the modes bike & ride and park & ride due to their very small share (3.2%) in the commute modal split. In addition, walking is grouped together with cycling as non-motorized active transport modes in the further analysis due to the following two main considerations: Firstly, the share of walking (3.7%) is much smaller compared to other modes of transport such as cars, public transport and cycling. Secondly, the difference in terms of speed and maximal distance covered between cycling and walking in these two active travel modes is much smaller compared to the difference between non-motorized travel modes and motorized travel modes.

8.1.1 Current commute modal split

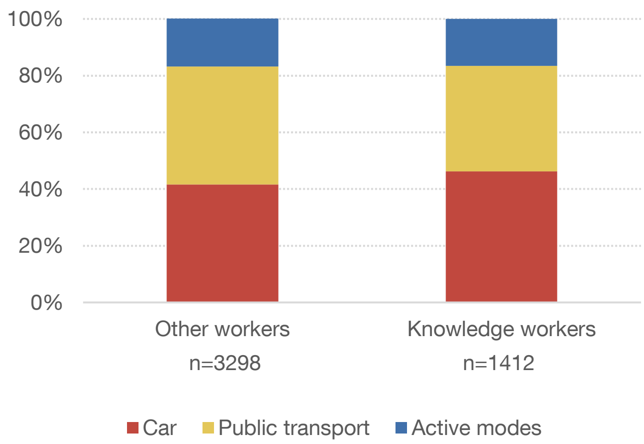


Figure 106. Commute modal split among knowledge workers and other workers.

As shown in Figure 106, the share of using cars, public transport and active modes are split 46.2%, 37.2% and 16.6% among knowledge workers. Among other workers, there is a nearly same share (41.6%) of commute using public transport and cars. The share of commuting with active modes amounts to 16.9%. There is no apparent differentiation between knowledge workers and other workers in terms of the commute modal split. The share of using cars as commute mode is slightly higher among knowledge workers than that of other workers, whereas the share of using public transport is slightly lower among knowledge workers than that of other workers.

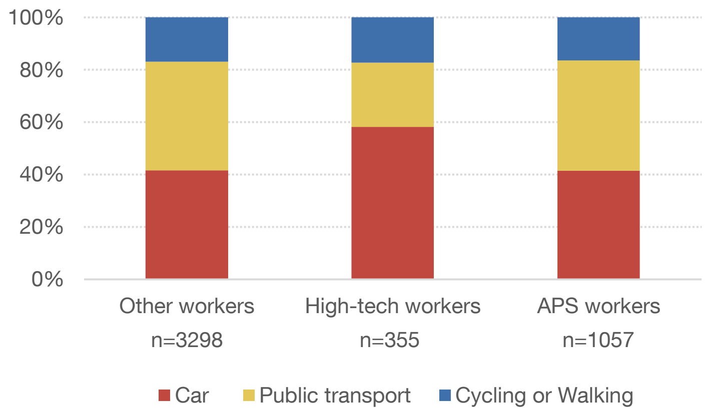


Figure 107. Commute modal split among workers in different employment sectors.

When further differentiating knowledge workers based on their employment sector (high-tech industries, APS sectors and other sectors), it is found that workers employed in APS sectors and other workers more frequently use public transport to reach their workplaces than workers in high-tech sectors (Figure 107). Interestingly, it is observed that the share of active modes is constant across these three groups.

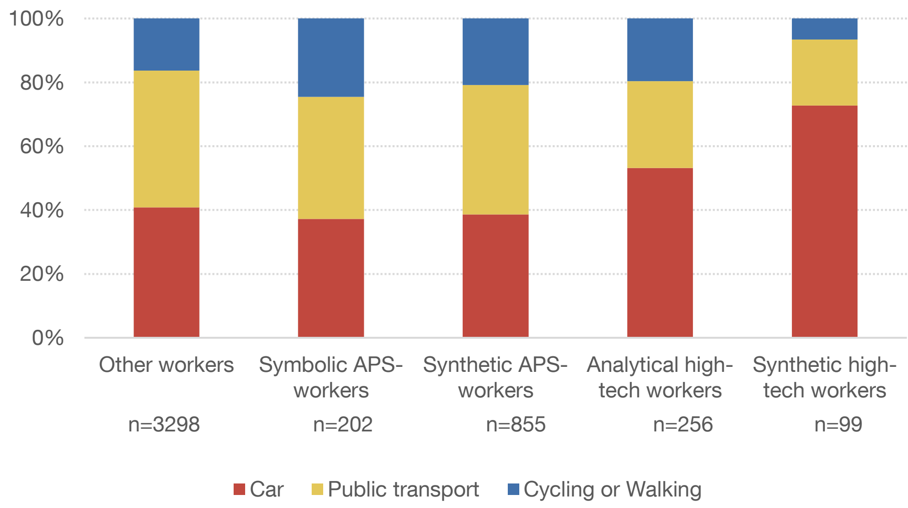


Figure 108. Commute modal split among workers using different bases in different employment sectors and other workers.

Next, the study further differentiates knowledge workers in high-tech or APS sectors based on the type of knowledge base applied in their jobs. Within the sample, the share of symbolic APS-workers, analytical high-tech workers, and synthetic APS-workers cycling or walking to reach their workplaces is two to three times larger than that of synthetic high-tech workers (Figure 108). Public transport is the main commuting mode among synthetic APS-workers, symbolic APS-workers and other workers. In contrast, half of analytical high-tech workers and 73% of synthetic high-tech workers use cars to commute.

8.1.2 Change of commute distance/mode after residential move

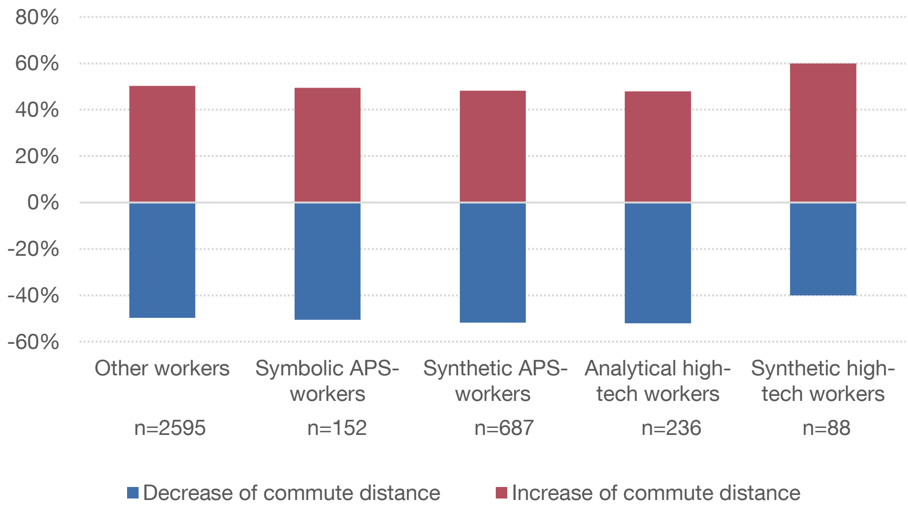


Figure 109. Change of commute distance among each group of workers after the residential move.

This section analyzes individual workers who change their residences and without changing their workplace locations. Figure 109 reveals that 60% of synthetic high-tech workers' commute distance has been extended, whereas the share is only 50% among all other groups of workers (symbolic APS-workers, synthetic APS-workers, analytical high-tech workers, as well as other workers). This is related to the finding in Chapter 6 that synthetic high-tech workers' residences are less concentrated in the region after residential moves. In addition, this also particularly corresponds to the finding in Chapter 7 that synthetic high-tech workers are more willing to tolerate long commute distances to improve dwelling size.

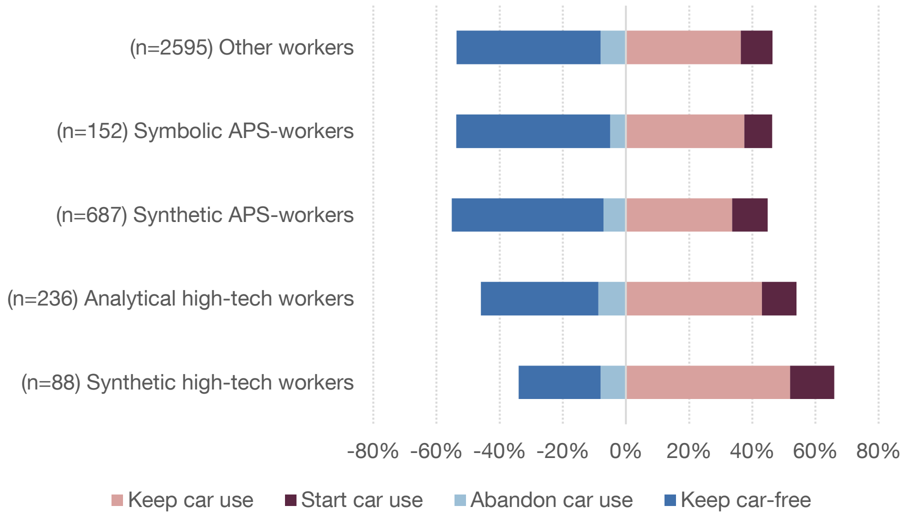


Figure 110. Shift of commute mode among each group of workers after the residential move.

The analysis of the change of the commute mode differentiates only between car-based and car-free commute modes (including public transport, cycling, and walking). Accordingly, there are four types of situations regarding the commute mode change: keep using cars to commute (used cars previously and currently); keep using car-free modes to commute (used car-free modes previously and currently); start car commute (previously used car-free modes and currently use cars); and abandon car commute (previously used cars and currently use car-free modes). It is noticed that among all groups of workers, the share of individuals who start car commute is larger than the share abandoning car commute after a residential move (Figure 110). Moreover, it is observed that the share of start car commute and keep car commute is highest among synthetic high-tech workers compared to other groups of workers. Analytical high-tech workers closely follow behind synthetic high-tech workers. In contrast, among symbolic APS-workers, synthetic APS-workers and other workers, the share of start car commute is almost offset by those who abandon car commute. Furthermore, their share of keep using car-free modes to commute is larger than that of keep using cars as commute modes.

8.1.3 Change of commute distance/mode after job change

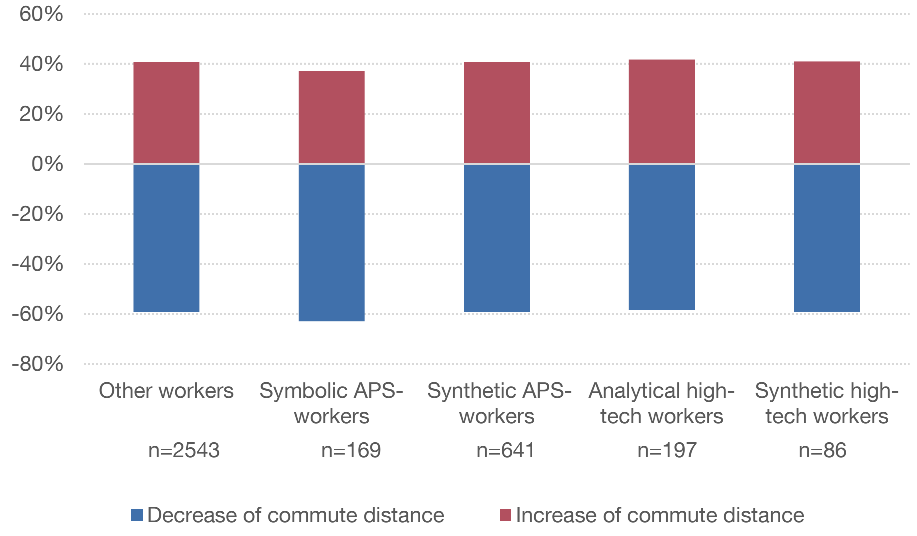


Figure 111. Change of commute distance among each group of workers after the job change.

When individuals change their jobs while keep their residences unchanged, almost the same share (60%) of people decrease the commute distance among all groups of workers (Figure 111). This corresponds to the previous finding that workplace location, i.e., job-housing proximity, is considered in addition to job prospects. This directly corresponds to the observation that more people abandon car commute compared to start car commute (Figure 112).

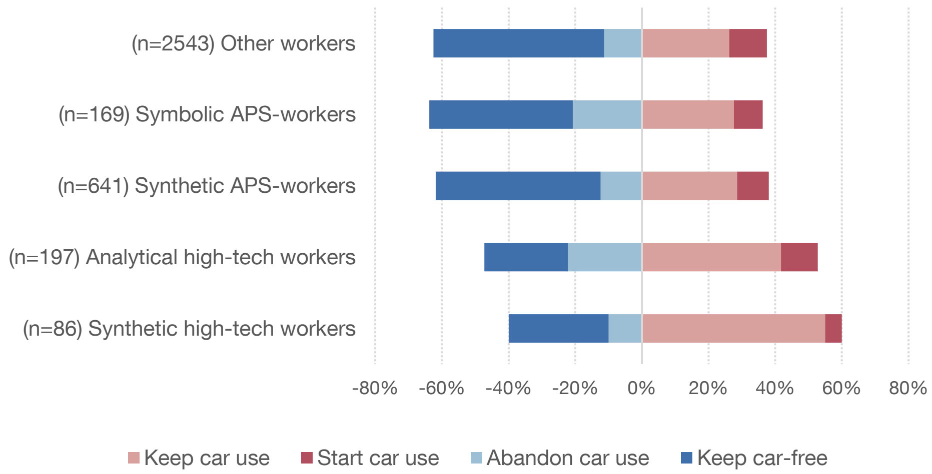


Figure 112. Shift of commute mode among each group of workers after the job change.

Furthermore, the above figures also indicate that, given the same change of commute distance after the workplace location change, the commute mode may change. Symbolic APS-workers and analytical high-tech workers are more sensitive to the decrease of commute distance and a larger share of them shift from car to car-free modes. This is associated to their relatively larger share of using active modes to commute (active travel modes is most sensitive to the change of the commute distance compared to public transport and cars).

8.1.4 Change of commute mode after joint residential move and job change

The change of the commute distance when individuals change both their residences and workplaces has already been shown in Figure 33 in Chapter 6. More individuals shorten the commute distance after a joint change of residence and workplace location. However, Section 8.1.2 shows that commute distance does not have a general effect one way or the other on residential change (50% increase and 50% decrease). Hence, it is very probable that shortened commute distance is largely a consequence of change of workplace location rather than residential move.

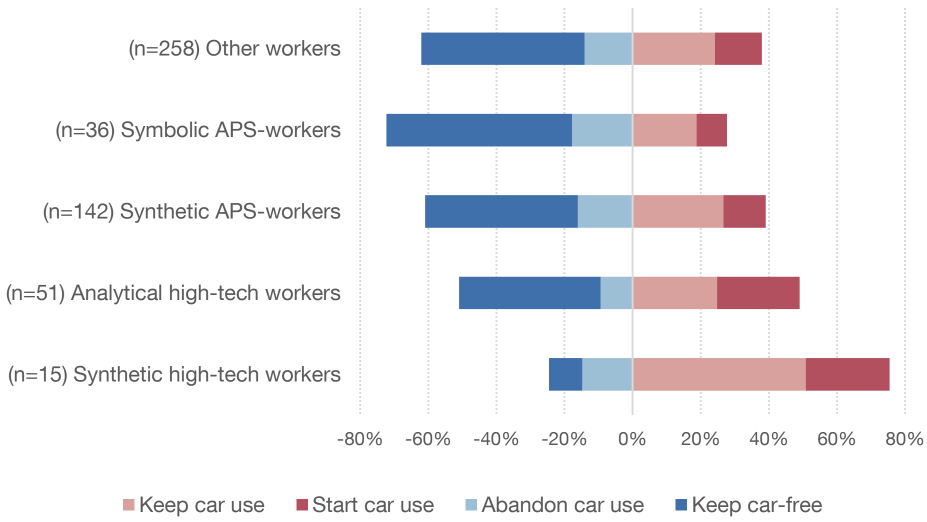


Figure 113. Shift of commute mode among each group of workers after the residential move and job change.

Regarding the shift of commute transport mode (Figure 113), it is shown that there is a the largest share of synthetic high-tech workers starting car commute after a joint change of job and housing, which corresponds well to the largest share of synthetic high-tech workers increasing commute distance. In addition, it is observable that a larger share of symbolic and synthetic APS-workers abandon car use compared to start car commute after a joint change of job and housing. Interestingly, there is a large share of analytical high-tech workers shifting from car-free to car-based modes. This to some extent expected, since travelling with active modes and by car have similar features in terms of detachment from surrounding people compared to public transport. The shift to car commute follows analytical high-tech workers' direct shift from active modes (sensitive to increase of commute distance) to cars upon the increase of commute distance.

8.1.5 Change of commute distance/mode after residential move and/or job change

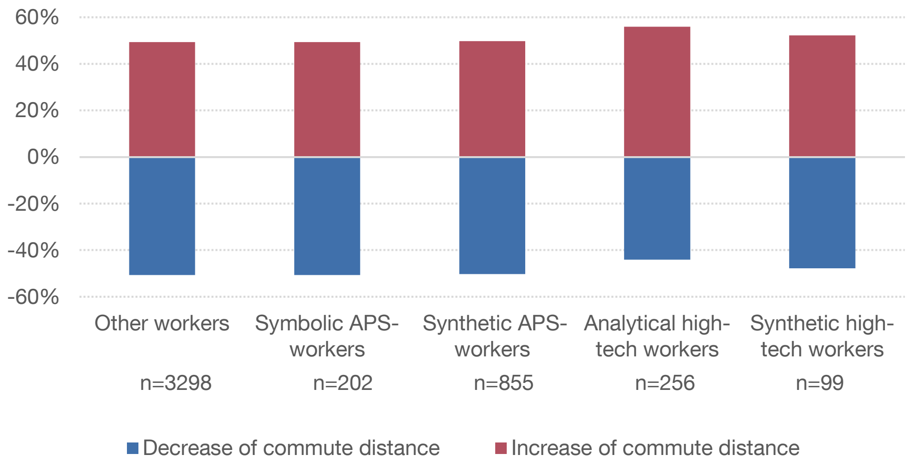


Figure 114. Change of commute distance among each group of workers after residential move and/or job change.

This analysis focuses on individuals who change either their residence or workplace location or both locations. As expected, Figure 114 shows that there is no apparent difference regarding the general change of the commute distance among all groups of workers. This is related to fact that in the sample more people (79.3%) move residences than change their jobs (61.8%). Results in previous sections show that residential moving is not associated with a dominant share of increasing or decreasing commute distance, whereas job change will very likely drive a decrease in the commute distance.

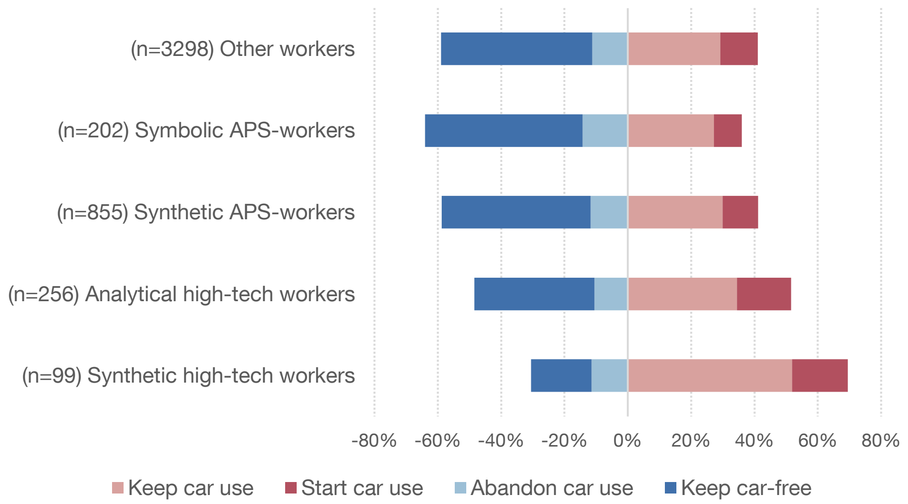


Figure 115. Shift of commute mode among each group of workers after the residential move and/or job change.

As shown in Figure 115, after the change of at least one of the two spatial anchors (residence and workplace location), the share of workers who keep using cars previously and currently increases continuously from the group of symbolic APS-workers, via synthetic APS-workers and analytical high-tech workers, to the group of synthetic high-tech workers. In contrast, the share of workers who keep using car-free modes decreases gradually. More than half of (51.9%) synthetic high-tech workers constantly use cars as the commute mode. In contrast, almost half of symbolic APS-workers (49.8%) keep using other travel modes instead of cars. In addition, the share shifting from car-free to car-based modes is larger than the opposite case among synthetic high-tech workers, whereas the share shifting to car-free modes from car-based modes is larger among symbolic APS-workers. The share shifting to car commute equals the share shifting to car-free commute modes among synthetic APS-workers. In contrast, the share who keep using cars to commute is same as the share who keep using other modes to commute among analytical high-tech workers. In addition, analytical high-tech workers' commute mode change is more similar to that of synthetic high-tech workers.

8.2 Knowledge base influences choice of the commute transport mode

Previous descriptive results present some differences regarding the commute mode choice and the change of commute mode among different groups of knowledge workers. This section continues to report on whether knowledge base indeed generates independent influences on the choice of commute mode.

8.2.1 Modelling the choice of commute transport modes

*Table 10. Results of multinomial logistic regression for commuting mode choice (Author's own calculation;*indicates 0.05 significant level; n=4087).*

Variables	Coefficients in Model 1 (Car as the reference)		Coefficients in Model 2 (Car as the reference)	
	Part 1: Transit	**Part 2: Active**	**Part 1: Transit**	**Part 2: Active**
Constant	0.20	4.10	0.07*	7.24*
Household type: Family (ref)				
Single-person	1.25	0.58*	1.21	0.54*
Single-parent	0.49	0.58	0.47	0.55
Two-person	0.95	0.61*	0.94	0.58*
Multi-person apartment	1.28	0.82	1.28	0.79
Education level: University degree (Ref)				
Without university degree	0.81*	0.44*	0.80*	0.47*
Gender: male (ref)				
Female	1.01	0.92	1.02	0.91
Income level: medium level (ref)				
Lowest income level	1.04	0.86	1.04	0.83
Highest income level	1.22	1.11	1.21	1.02
Commuting distance along road network	1.07	0.18*	1.09	0.18*
Travel time PuT/Car=3 (Ref)				
Travel time PuT/Car=1	0.71	2.94	0.76	5.21*
Travel time PuT/Car=2	1.97*	1.57*	1.95*	1.63*
Travel time PuT/Car=4	0.55*	0.72	0.54*	0.75
Travel time PuT/Car=5	0.32*	0.60*	0.32*	0.61*
Stated preference of car travel at residence (Ref)				
No Stated preference	1.62*	3.46*	1.63*	3.46*
Stated preference of car travel at workplace (Ref)				
No Stated preference	14.88*	19.30*	15.33*	20.29*
Private car (Ref)				
Company car	0.15*	0.08*	0.14*	0.07*
According to need or car sharing	6.62*	4.90*	6.75*	5.05*
No car	19.11*	12.55*	19.30*	12.30*
Workplace location: Non-Central workplace (Ref)				
Central workplace	2.05*	1.75*	3.32*	1.73*
Residence location: Non-Central located residence (Ref)				
Central residence	1.06	1.32	1.93*	1.77*
Subgroups: high-tech workers (Ref)				
Other workers			2.39*	5.42*
Analytical workers			1.36	**11.94***
Symbolic KW			1.80	**5.53***
APS KW			**2.80***	**7.32***
McFadden R square	**0.470**		**0.475**	

Since commute modes are differentiated into three alternatives, namely car, public transport and active travel modes, multinomial logistic modelling is applied here. The commuting mode is firstly predicted using variables listed in Model 1 in Table 10. Workplace location, the ratio of travel time using public transport versus car (Figure 116), and stated importance of car-friendly travel near residence and workplace (Figures 117-118) have the largest positive correlation coefficients with the commuting mode. Model 1 accounts for 47.0% of the modal split of commuting trip. Afterwards, adding the new categorical variable of knowledge worker group increases the R square to 0.475 in Model 2 (Table 10). Similar to residential location choice, the commuting mode is also largely explained by the socio-demographic variables such as household size and mobility preference. Nevertheless, it is noticed that the likelihoods of commuting mode choice are statistically significantly different among each type of knowledge worker. Synthetic APS-workers are more likely to use public transport than a car to commute compared to synthetic high-tech workers. Analytical high-tech workers, symbolic APS-workers, and synthetic APS-workers are more likely to use active modes than a car, compared to synthetic high-tech workers.

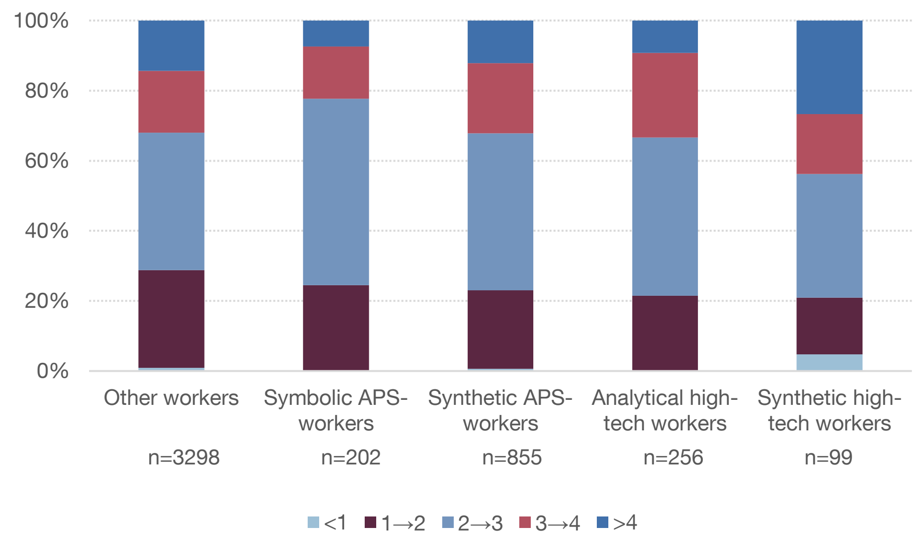


Figure 116. Distribution of commute time ratio using public transport and cars among each group.

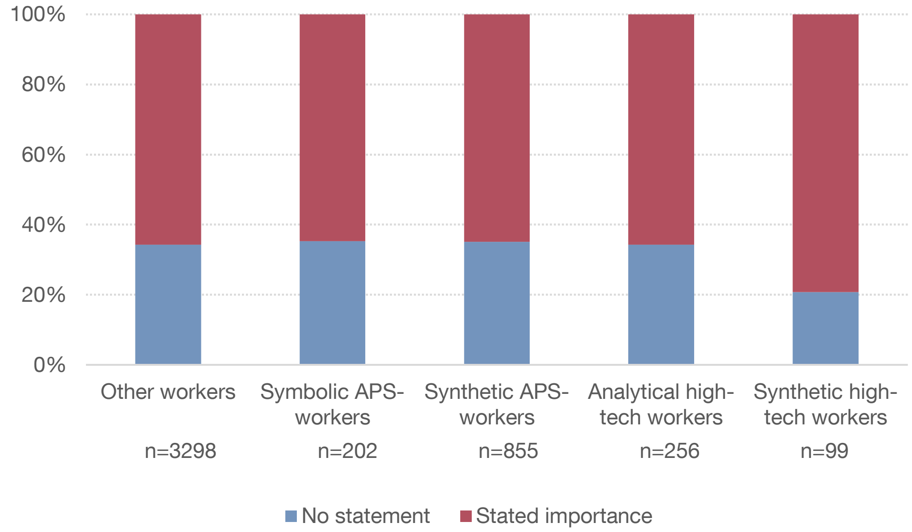


Figure 117. Distribution of stated importance of car at residence among each group.

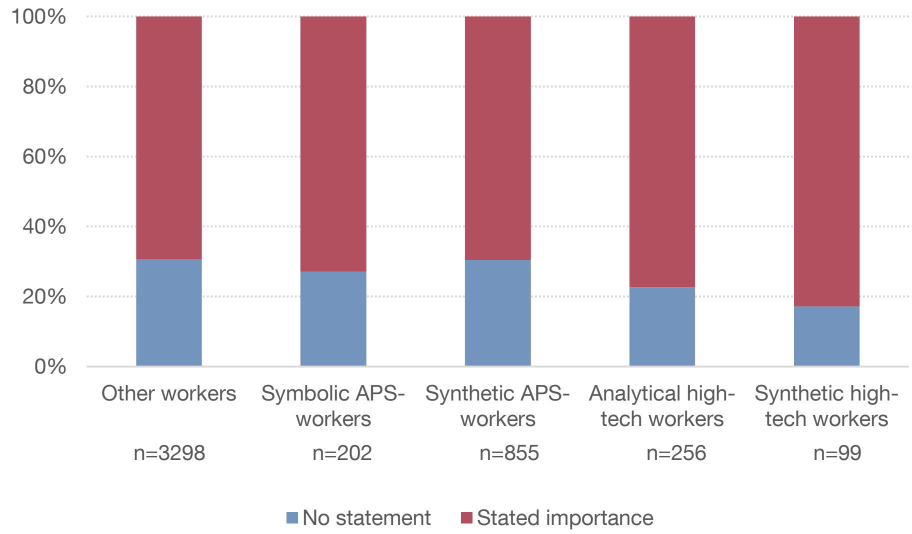


Figure 118. Distribution of stated importance of car at workplace among each group.

Even when factors such as residential and workplace location and car ownership are considered, the categorical variable of knowledge worker group still correlates significantly with the choice of commute mode. This confirms the third hypothesis that symbolic APS-workers tend more frequently to use public transport or active travel modes to commute, whereas synthetic high-tech workers depend on cars to reach their workplaces. Furthermore, various commuting modes of different knowledge workers do appear to relate to their locations of residence and workplace, since the choice of commuting mode depends on a correspondence between accessibility at residence and workplace. This suggests that the third hypothesis actually relates to the first hypothesis. Different residential locations contribute to the variety of commuting modes. The share of synthetic APS-workers using public transport is almost twice as high as synthetic high-tech workers, which may partially relate to the fact that the share residing in central areas among synthetic high-tech workers is 10% less than synthetic APS-workers (Figure 61). In addition, different types of knowledge workers have different workplace locations. For instance, 76% of symbolic APS-workers' workplaces are located in central areas, whereas the share among synthetic high-tech workers is only 50% (Figure 62). This also affects the choice of commuting mode.

8.2.2 Different sensitivities of commute mode choice to location attributes among each group of workers

After verifying the statistical significance of the impact of knowledge base in choice of commute mode, this section examines the underlying reasons for this difference, namely the different sensitivities of their commute mode choice to each influencing factor (the built environment, socio-demographic situation) among each group of knowledge workers. Upon the choice of commute transport mode, mobility preference has to be weighed against the objective constraint condition including the spatial characteristics (accessibility offered by transport infrastructure) as well as the socio-demographic situation (monetary and time constraint). The spatial characteristics of the residence and workplace are measured with the commute distance, and the ratio of commute time using public transport compared to cars. Different sensitivities to the existing built environment are associated with the different mobility preference, which together influence the choice of commute transport mode. As shown in Table 11, firstly, symbolic APS-workers are more responsive to the reduced ratio of commute time using public transport compared to using cars, compared to synthetic high-tech workers (when the ratio is reduced from 3:1 to 2:1). This means that the underlying larger inclination for public transport among symbolic APS-workers also contributes to their larger likelihood of using public transport. Secondly, analytical high-tech workers are less responsive to abandoning active modes when the commute distance increases compared to symbolic APS-workers. This indicates the larger preference for using active modes among analytical compared to symbolic APS-workers. Thirdly, among symbolic APS-workers, single-person households are significantly more likely to use public transport than cars compared to family households, whereas this is not observed among synthetic high-tech workers.

Table 11. Modelling the choice of commute transport mode among each group of workers (Author's own calculation).

Public transport to cars	Other workers (n=3298)		Analytical high-tech workers (n=256)		Symbolic APS workers (n=202)		Synthetic APS workers (n=855)		Synthetic high-tech workers (n=99)	
Variables	Significance	Exp(B)	Significance	Exp(B)	Significance	Exp(B)	Significance	Exp(B)	Significance	Exp(B)
Constant	0.27	1.97	0.04	422.14	0.17	155373.93	0.02	21.55	0.90	2.38
Commute distance	0.00	0.82	0.01	0.52	0.16	0.31	0.00	0.69	0.76	0.82
Gender: Male (ref)										
Female	0.79	1.03	0.05	0.38	0.19	0.13	0.79	0.93	0.16	5.21
Household type: Family (ref)										
Single-person	0.57	0.91	0.97	1.02	0.05	***7.92***	**0.08**	**0.53**	0.36	0.24
Single-parent	0.10	0.51	1.00	0.00	0.99	0.00	0.99	0.99	0.70	9.33
Two-person	0.01	0.68	0.57	1.39	0.76	0.70	0.47	1.20	0.36	0.46
Income level: medium level (ref)										
Lowest income level	0.58	0.91	0.22	0.21	0.01	0.00	0.50	1.46	0.25	0.01
Highest income level	0.00	1.54	0.32	0.62	0.95	0.91	0.54	1.17	0.42	0.47
Education level: University degree (Ref)										
Without university degree	0.00	0.66	0.17	0.38	0.35	0.17	0.05	0.61	0.83	0.82
Travel time PuT/Car=3 (Ref)										
Travel time PuT/Car=1	0.89	0.93		0.00	1.00	0.00	0.25	0.19	0.10	0.01
Travel time PuT/Car=2	0.00	3.02	0.37	0.60	0.05	***18.98***	0.00	2.16	0.05	***7.63***
Travel time PuT/Car=4	0.00	0.40	0.00	0.08	0.64	0.45	0.00	0.18	0.09	0.07
Travel time PuT/Car=5	0.00	0.10	0.08	0.16	0.14	0.02	0.00	0.06	0.30	0.34
Private car (Ref)										
Company car	0.00	0.25	0.28	0.05	0.08	0.02	0.00	0.13	0.57	0.33
According to need or car sharing	0.00	10.62	0.00	8.39	0.98	2.18	0.00	5.25	0.91	1.13
No car	0.00	28.80	0.00	102.94	0.98	13.89	0.00	18.04	0.24	5.98
Detached houses (Ref)										
Apartment	0.00	3.97	0.21	3.25	0.78	1.49	0.00	3.99	0.32	3.68
Terrace houses	0.00	2.84	0.97	1.04	0.99	0.00	0.02	2.94	0.94	74.41
Semi-detached houses	0.00	2.11	0.91	1.17	0.62	2.83	0.89	0.94	0.39	3.61

Active modes to cars	Other workers (n=3298)		Analytical high-tech workers (n=256)		Symbolic APS workers (n=202)		Synthetic APS workers (n=855)		Synthetic high-tech workers (n=99)	
Variables	Significance	Exp(B)	Significance	Exp(B)	Significance	Exp(B)	Significance	Exp(B)	Significance	Exp(B)
Constant	0.00	15.57	0.00	15.65	0.98	40.31	0.00	20.69	0.36	9.21
Commute distance	0.00	0.16	**0.00**	**0.13**	0.00	0.00	0.00	0.10	**0.18**	**0.27**
Gender: Male (ref)										
Female	0.02	0.70	0.27	0.50	0.21	0.08	0.89	1.05	0.88	1.29
Household type: Family (ref)										
Single-person	**0.01**	**0.50**	**0.04**	**0.13**	0.54	9.89	**0.01**	**0.25**	0.57	0.00
Single-parent	0.32	0.60	0.10	45.62	1.00	0.00	0.55	1.78	0.55	0.00
Two-person	0.00	0.45	0.03	0.17	0.02	0.01	0.26	1.53	0.76	0.66
Income level: medium level (ref)										
Lowest income level	0.22	0.74	0.79	0.70	0.11	0.00	0.04	0.19	0.61	28.51
Highest income level	0.00	1.80	0.07	0.28	0.44	4.50	0.08	0.53	0.92	0.85
Education level: University degree (Ref)										
Without university degree	0.00	0.39	0.01	0.06	0.03	0.00	0.00	0.17	0.56	0.44
Travel time PuT/Car=3 (Ref)										
Travel time PuT/Car=1	0.00	7.06		0.00		0.00	0.80	1.69	0.38	0.01
Travel time PuT/Car=2	0.00	1.94	0.12	0.20	0.56	3.66	0.07	2.11	0.68	2.31
Travel time PuT/Car=4	0.03	0.66	0.01	0.10	0.24	0.06	0.00	0.25	0.92	1.23
Travel time PuT/Car=5	0.00	0.37	0.18	0.21	0.84	0.59	0.00	0.11	0.47	3.01
Private car (Ref)										
Company car	0.06	0.34	0.99	0.00	0.99	0.00	0.00	0.01	0.82	0.55
According to need or car sharing	0.00	8.74	0.00	28.82	0.98	2.12	0.00	4.92	0.76	0.56
No car	0.00	26.22	0.00	185.75	0.99	9.26	0.00	223.46	0.27	12.19
Detached houses (Ref)										
Apartment	0.28	1.41	0.11	174.23	0.99	5.89	0.80	0.84	0.44	4.57
Terraced houses	0.32	1.52	0.24	43.71	1.00	0.00	0.31	2.28	0.79	5.99
Semi-detached houses	0.03	0.35	1.00	0.00	1.00	8.16	0.71	0.73	0.92	1.34
Nagelkerke R Square					**0.607**					

8.3 Knowledge base influences the joint choice of residential location and commute mode

After the separate modelling of residential locations and commute mode choices in the previous chapters, this section continues with a joint choice modelling by combining the choice of residential location and commute mode.

8.3.1 Descriptive analyses

Next, we look at the joint choice of the residential location and commute mode (Figure 119). Almost 60% of synthetic high-tech workers live in peripheral areas and depend on cars to commute. The share living in central areas and using public transport to commute is largest among symbolic APS-workers. One fourth of synthetic APS-workers live in central areas and commute with public transport and another one-quarter of them live in peripheral areas and use cars to commute. Analytical synthetic high-tech workers are similar to synthetic high-tech workers in terms of location choice, but the shares using active modes in either central areas or peripheral areas are much larger than synthetic high-tech workers.

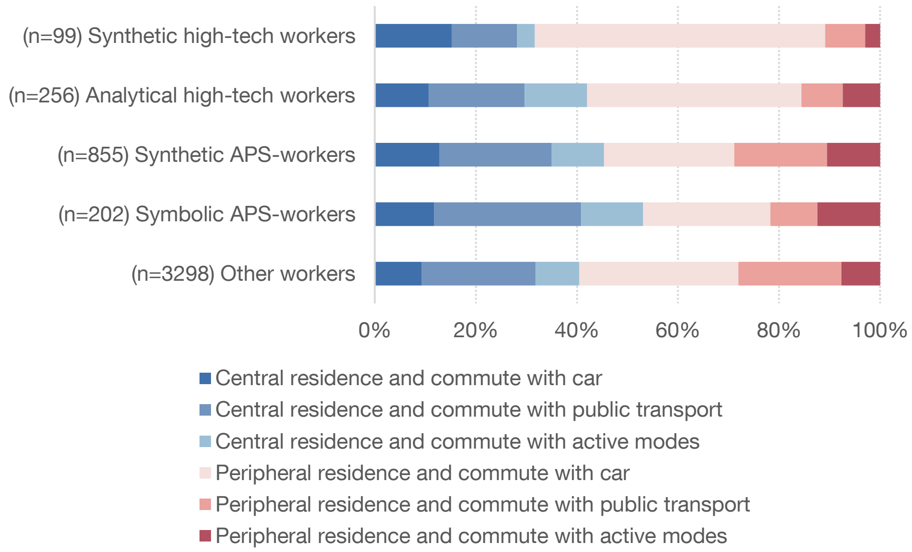


Figure 119. Choice of residential location and commute mode among group of workers.

8.3.2 Joint choice of residential location and commute mode

As shown in Table 12, conventional socio-demographics and spatial structural attributes explain 30.5% of the total variations regarding joint choice of residential location and commute mode. Highest income level both significantly positively associates with living in central areas. Individuals with the lowest income level tend to have a smaller likelihood of living in central areas and commute by cycling or walking, than living in a peripheral location and commuting with cars. Single-person households have a larger likelihood of living in central areas and using public transport than family households do. Two-person households also tend to live in central areas and commute with public transport than having a peripheral residence and using cars to commute, comparing with family households.

A central workplace tends to encourage individuals to choose a central residential location and use public transport or active modes to commute. Moreover, even if the residence is within peripheral areas, a central workplace tends to encourage the usage of public transport. As expected, when the ratio of commute time using public transport and cars is smaller than the average ratio (2.7), individuals are more likely to use public transport regardless of the residential location. Auto-affinity also significantly associates with the joint choice. Individuals without auto-affinity are more likely to live in central areas and use public transport or active modes to commute. Even when these individuals live in peripheral locations, they still more frequently use public transport or active modes instead of cars to reach their workplaces. Lastly, as expected, the absence of a private car, referring to the situation of no car, according to the need, or car sharing, is significantly associated with a car-independent lifestyle. In contrast, the company car in general associates with a larger likelihood of individuals using cars even when they live in central areas and simultaneously discourages the usage of other modes regardless of the residential location.

Table 12. Results of the basic model regarding the joint residential location and commute mode choice (Author's own calculation; indicates 0.05 significant level; Odds ratio marked in bold are explained in detail in the text; n= 5142)*

	Central residence, commute with car	**Central residence, commute with public transport**	**Central residence, commute with cycling/ walking**	**Peripheral residence, commute with public transport**	**Peripheral residence, commute with cycling/ walking**
Variables	Exp(B)	Exp(B)	Exp(B)	Exp(B)	Exp(B)
Constant	0.21	0.41	0.08	0.73	0.32
Gender: Male (ref)					
Female	0.91	0.94	1.00	1.07	0.99
Household type: Family (ref)					
Single-person	2.89	**3.01***	2.51	1.63	1.10
Single-parent	2.64	1.23	3.57	0.66	1.49
Two-person	1.29	**1.50***	1.17	0.95	0.66
Multi-person apartment	1.50	1.35	1.23	1.21	0.91
Income level: medium level (ref)					
Lowest income level	0.62	0.84	**0.77***	0.97	0.81
Highest income level	**1.45***	**1.35***	**1.29***	1.30	1.54
Workplace location: Peripheral workplace (Ref)					
Central workplace	1.37	**5.01***	**6.61***	**4.52***	1.27
Ratio of commute time using public transport and car: Ratio larger than or equal to 2.7 (Ref)					
Ratio of commute time smaller than 2.7	1.58	**3.85***	0.87	**3.64***	**0.67***
Auto affinity (Ref)					
Without auto affinity	1.29	**17.53***	**11.24***	**4.97***	**4.16***
Access to a car: Private car (Ref)					
Company car	**2.18***	**0.29***	**0.12***	**0.31***	**0.26***
According to arrangement or car sharing service	0.59	**8.99***	**9.51***	**6.74***	**5.78***
No access	3.16	**26.51***	**21.93***	**13.46***	**15.48***
Nagelkerke R Square			**0.305**		

Remark: The scenario of peripheral residence and commute with cars is set as the reference category in the multinomial logistic regression.

Based on the basic model in Table 12, when we further add the categorical variable of knowledge worker group in the model (Table 13), R square increases slightly from 0.305 to 0.324. As expected, symbolic and synthetic APS-workers are more likely to reside in central areas and commute with public transport or active modes than live in peripheral residential location and commute with cars than synthetic high-tech workers. However, it was found, unexpectedly, that synthetic APS-workers also show a greater tendency to live in peripheral areas and commute with public transport or active modes. Analytical high-tech workers show a greater tendency to use active modes and live in peripheral areas than using cars and living in the peripheral areas compared to synthetic high-tech workers, which partially contradicts our hypothesis. Other workers are most likely to live in peripheral areas and use public transport to commute than the reference scenario compared to synthetic high-tech workers. Moreover, other workers also tend to live in central areas and commute with public transport than living in a peripheral location and commute with cars than synthetic high-tech workers.

Table 13. Modelling results of the joint residential location and commute mode choice after adding the categorical variable of knowledge worker group (Author's own calculation; indicates 0.05 significant level; Odds ratio marked in bold are explained in detail in the text; n= 5142)*

	Central residence, commute with car	**Central residence, commute with public transport**	**Central residence, commute with cycling/walking**	**Peripheral residence, commute with public transport**	**Peripheral residence, commute with cycling/walking**
Variables	Exp(B)	Exp(B)	Exp(B)	Exp(B	Exp(B)
Constant	1.91	7.07	3.97	0.00	3.86
Gender: Male (ref)					
Female	0.94	0.86	0.71*	1.17	0.59*
Household type: Family (ref)					
Single-person	1.99	2.42*	1.23	1.79*	0.71
Single-parent	1.73	0.89	1.21	0.62	0.66
Two-person	1.12	1.39*	0.88	0.97	0.58
Multi-person apartment	1.06	1.08	0.79	1.07	0.93
Income level: medium level (ref)					
Lowest income level	0.70	0.85	0.62*	0.98	0.69
Highest income level	1.35*	1.52*	1.51*	1.39	2.01
Workplace location: Peripheral workplace (Ref)					
Central workplace	1.45	6.71*	7.74*	5.94	1.26
Ratio of commute time using public transport and car: Ratio larger than or equal to 2.7 (Ref)					
Ratio of commute time smaller than 2.7	1.59*	3.87*	0.87	3.67*	0.69*
Auto affinity (Ref)					
Without auto affinity	1.11	3.38	6.39	2.68	8.47
Access to a car: Private car (Ref)					
Company car	1.48*	0.19*	0.06*	0.26*	0.08*
According to arrangement or car sharing service	0.64	10.38*	12.29*	8.69*	6.67*
No access	**3.35***	**41.84***	**32.98***	**25.14***	**12.54***
Subgroups: synthetic high-tech workers (Ref)					
Other workers	1.43	**1.92***	2.90	**2.45***	3.43
Analytical high-tech workers	1.07	1.33	2.43	0.64	**5.57***
Symbolic APS-workers	2.19	**2.60***	**4.62***	1.97	2.87
Synthetic APS-workers	1.94	**2.84***	**5.96***	**2.59***	4.63
Nagelkerke R Square			**0.324**		

Remark: The scenario of peripheral residence and commute with cars is set as the reference category in the multinomial logistic regression.

8.4 The relation between workplace location change and commute mode shift

Since the previous models show that the location of the workplace is highly correlated with the choice of commute mode, the study now examines whether the change of workplace location influences the possibility of change of commute mode. The analysis focuses on individuals who have only changed their jobs during the last three years to examine specifically the influence of workplace location on the choice of commute mode. Similarly, socio-demographic factors should also be included in the model to control for their effects. As the dependent variable in the model is the change of the commute mode, only car commute and car-free commute are differentiated to reduce the complexity of the interpretation. Four possible alternative outcomes are: keep using cars to commute, abandon car commute (previously used the car but currently use car-free modes to commute), start car commute (previously used the car-free modes but currently use cars to commute), and keep using car-free modes to commute. Start car commute is selected as the reference category of the dependent variable in the multinomial model. The interpretation focuses on comparing 'abandon car commute' to 'start car commute'. The analysis firstly uses workplace centrality in terms of within or outside of central areas as the proxy for workplace location, and afterwards uses the specific indicators such as the number of services near the workplace, the distance to the residence, as well as the distance to the closest public transport station.

8.4.1 Change of centrality of workplace location and commute mode shift

Firstly, the binary differentiation of central areas and non-central areas as the overall measurement of the workplace location is used in the model. The independent variable, namely the change of workplace centrality has four possibilities or categories: both previous and current workplaces within central areas; both previous and current workplaces outside of central areas; previous workplace within central areas, but current workplace outside of central areas; and previous workplace outside of central areas, but current workplace within central areas (the reference scenario). The dependent variable is either abandon car use after job change or start car use after job change (the reference category). Changing the workplace location from outside of central areas to within central areas is set as the reference scenario. Results in Table 14 show that when workplace location is changed from within central areas to outside of central areas, the possibility of abandoning car commute is statistically significantly lower than starting to use a car.

Table 14. The association between change of workplace centrality and commute mode shift (Author's own calculation; n=3636).

Variables	B	Sig.	Exp(B)
Constant	5.02	0.00	
Subgroups: Other workers (ref)			
Analytical workers	0.58	0.47	1.78
Symbolic workers	0.86	0.27	2.36
High-tech workers	0.17	0.77	1.19
APS workers	0.68	0.21	1.97
Change of workplace: workplace move into central areas (ref)			
Workplace remain in non-central areas	-0.73	0.16	0.48
Workplace remain in central areas	-1.31	0.00	0.27
Workplace move out from central areas	**-2.01**	**0.00**	**0.13**
Gender: Female (ref)			
Male	-0.40	0.24	0.67
Income level: high income level (ref)			
Low income level	-0.94	0.14	0.39
Medium income level	0.23	0.53	1.26
Type of household: Family household (ref)			
Single person household	0.68	0.33	1.98
Single parent	1.08	0.32	2.93
Two person household	-0.44	0.44	0.64
Education level: with university degree (ref)			
Without university level	0.01	0.99	1.01
Access to car: no access (ref)			
Private car	-2.29	0.03	0.10
Company car	-3.06	0.02	0.05
According to arrangement or car sharing	-1.72	0.15	0.18
Ownership of public transport pass: with public transport pass (ref)			
Without public transport pass	-2.35	0.00	0.10
Nagelkerke R Square		**0.589**	

8.4.2 Change of accessibility at the workplace location and commute mode shift

After adding direct measurement indicators such as change of the number of services near the workplace, change of commute distance, and change of the distance to the closest public transport station from the workplace, the correlation between the workplace centrality and the shift of commute mode becomes insignificant (Table 15). This is easily understood since it is actually these specific spatial attributes at the workplace shaping individuals' considerations and influencing their choice between car commute and car-free commute, rather than the centrality of the workplace.

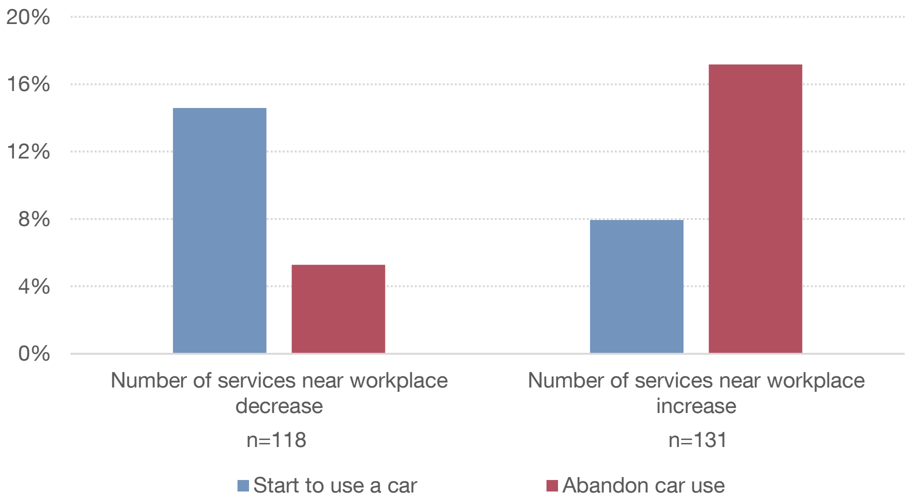


Figure 120. Change of number of services at workplace and start or abandon the car commute.

A regression analysis has been applied to integrate the service supply information. The overall number of services is the regression outcome of these four types of services: daily shopping and services, long-term shopping and services, cultural & gastronomic facilities, and leisure facilities. Figure 120 shows that more individuals are willing to abandon the car commute when the number of services near the new workplace increases, whereas this is opposite when the number of services reduces after the job change. This is also statistically significant in the results of modelling (Table 15). In addition, individuals with an increase of commute distance after a job change are less likely to abandon car commute compared to starting to use a car to commute. Lastly, similar to the effect of the commute distance change, if the distance to the closest public transport station increases after the change of the workplace location, individuals are less likely to abandon car commute compared to start car commute.

Table 15. The association between the change of location characteristics of the workplace and the commute mode shift. (Author's own calculation; n=3636).

Variables	B	Sig.	Exp(B)
Intercept	3.26	0.00	
Change of commute distane	**-0.30**	**0.03**	**0.74**
Change of number of services	**1.08**	**0.00**	**2.96**
Change of distance to closest public transport station	**-0.34**	**0.01**	**0.71**
Subgroups: Other workers (ref)			
Analytical workers	0.17	0.86	1.18
Symbolic workers	**1.55**	**0.09**	**4.72**
High-tech workers	0.37	0.56	1.44
APS workers	0.57	0.35	1.77
Gender: Female (ref)			
Male	-0.16	0.68	0.85
Income level: high income level (ref)			
Low income level	-1.72	0.02	0.18
Medium income level	-0.05	0.90	0.95
Type of household: Family household (ref)			
Single-person household	1.22	0.13	3.39
Single-parent	1.42	0.22	4.14
Two-person household	-0.01	0.99	0.99
Education level: with university degree (ref)			
Without university degree	0.19	0.67	1.21
Car access: according to arrangement or no car (ref)			
Private or company car	-1.67	0.00	0.19
Ownership of public transport pass: with public transport pass (ref)			
Without public transport pass	-2.78	0.00	0.06
Nagelkerke R Square		**0.664**	

Symbolic APS-workers show a statistically greater tendency to change the commute mode from car to car-free modes, even when the change of characteristics of the workplace location is considered in the model (but at a significance level of 0.10). Compared to the previous cross-sectional model, this provides stronger evidence that symbolic APS-workers' knowledge production mode shapes a larger preference for car-independent modes.

Given change of workplace location considered, symbolic knowledge still influences commute mode shift

8.5 The relation between residence location change and commute mode shift

Since commute relates to both spatial anchors (residence and workplace), the analysis now examines the impact of residence change on the commute mode shift. Similar to the impact of the workplace location change, if the accessibility of the residence (e.g. measured by an increase of the number of overall services nearby) after moving increases, it is also statistically significant that individuals are more likely to abandon car commute compared to starting car commute (Table 16).

Table 16. Residential location change and the commute mode shift (Author's own calculation; n=3754)

Variables	B	Sig.	Exp(B)
Constant	6.43	0.00	
Commute distance	-0.64	0.00	0.53
Gender: Female (ref)			
Female	-0.04	0.89	0.96
Type of household: Family household (ref)			
Single person household	0.01	0.98	1.01
Single parent	0.00	1.00	1.00
Two person household	-0.54	0.09	0.59
Shared-living households	-0.52	0.51	0.59
Income level: medium income level (ref)			
Low income level	0.60	0.42	1.81
High income level	0.52	0.11	1.69
Education level: with university degree (ref)			
With university degree	0.19	0.53	1.21
Mobility preference: Stated preference of car friendly travel at residence (ref)			
No stated preference of car friendly travel at residence	-0.28	0.44	0.76
Mobility preference: Stated preference of car friendly travel at workplace (ref)			
No stated preference of car friendly travel at workplace	2.49	0.00	12.00
Car access: private car (ref)			
Company car	-1.05	0.19	0.35
According to need or car sharing	0.29	0.55	1.34
No car	2.18	0.04	8.85
Workplace location: outside central areas (ref)			
Workplace within central areas	0.17	0.58	1.19
Change of residential location: move out from central areas to non-central areas (ref)			
Residence moved into central areas	**-1.65**	**0.00**	**0.19**
Nagelkerke R Square		0.603	

8.6 Summary of key findings

- The differences in commute modal split exist in groups differentiated by knowledge base rather than employment sector. Whether there is a single or joint change of residence and workplace, there is a clear differentiation between synthetic high-tech workers and all other groups of workers in terms of their constant usage of cars and car-free commute modes.
- The residential move tends to result in a larger share of individuals increasing the commute distance, whereas a job change tends to lead to a decrease of the commute distance.
- The commute mode is closely related to the commute distance. The commute mode shift is quite responsive to the change of the commute distance. In addition, commute mode shift is more responsive to the job change than residential change.
- Synthetic APS-workers are more likely to use public transport than a car to commute compared to synthetic high-tech workers. Analytical high-tech workers, symbolic APS-workers, and synthetic APS-workers are more likely to use active modes than a car, compared to synthetic high-tech workers.
- The choice of commute transport mode among symbolic APS-workers and analytical high-tech workers have different sensitivities to location attributes compared to other groups.
- Symbolic and synthetic APS-workers are more likely to reside in central areas and commute with public transport or active modes than live in peripheral residential locations and commute with cars than synthetic high-tech workers. However, synthetic APS-workers also show a greater tendency to live in peripheral areas and commute with public transport or active modes. Analytical high-tech workers show a greater tendency to use active modes and live in peripheral areas.
- Even when change of workplace location is considered in the model, symbolic APS-workers are still more likely to abandon the car commute compared to synthetic high-tech workers.
- When the accessibility of workplace or residence is improved, individuals are more likely to abandon car commute compared to starting to use cars to commute.

Part V DISCUSSION AND CONCLUSIONS

9 Discussion

In this chapter, several points raised in each chapter of the results will be firstly discussed. Following this, the interrelated residential locations, residential trade-offs and the choice of commute mode will be combined and discussed in an integrated way.

9.1 Residential location of knowledge workers and spatial (de-)concentration process

Role of residence: as a place for living, or as a place for production (workplace-unbound knowledge creation)

Knowledge workers select the optimal location that maximizes their - perceived utility. Apart from the well-studied location amenities and the accessibility to workplace, other aspects are also essential in explaining location choices of knowledge workers. Frenkel, Bendit and Kaplan (2013b) depart from the lifestyle perspective and find that cultural-oriented lifestyle adds to the possibility of living in central areas (Frenkel, Bendit and Kaplan 2013b). Kaplan, Grünwald and Hirte (2016) confirm the significance of social networks in the inter-regional migration of knowledge workers (Kaplan, Grünwald and Hirte 2016). Burger, van der Knaap and Wall (2014) reveal the different commute patterns between highly qualified workers and less well educated workers in the Randstad region (Burger, van der Knaap and Wall 2014). This study takes an approach from the perspective of the specific knowledge base applied in the occupation to investigate the heterogeneous spatially-related choices among subgroups of knowledge workers. Different knowledge creation modes are associated with different roles of residence they perceive in their career and different responsiveness of the residential location to the interaction types required in their jobs. Knowledge creation among synthetic high-tech workers is more dependent on their workplaces, since their job-related tasks in many cases demand certain equipment and facilities. Therefore, the living and working space of synthetic high-tech workers are relatively independent/separated from each other. Their choice of residence location is based mainly on residential-related amenities. Indeed, synthetic high-tech workers frequently mention the importance of the noise and safety level near the residence, as well as the school facilities compared to other groups. In addition, the share of synthetic high-tech workers improving the accessibility of residence to schools is almost twice as much as the share of symbolic APS-workers and synthetic APS-workers. These all suggest that the residential locations of synthetic high-tech workers are more driven by the attributes of the dwelling and amenities of the residential neighborhood, relatively independent of the fixed workplace. In contrast, synthetic APS-workers, symbolic APS-workers, and analytical high-tech workers relatively frequently also work from home. Therefore, these workers would also have a different perspective on selecting residential location compared to synthetic high-tech workers, since the residence functions not only as a place to live but also as a place to work (Ellen and Hempstead 2002: 752). The residence might be also regarded as an important spatial anchor for reaching other customers and other cooperation partners among symbolic APS-workers, synthetic APS-workers and analytical high-tech workers. In addition, whereas the exchange of analytical knowledge among analytical high-tech workers is relatively independent of the specific context, knowledge exchange and interaction among symbolic and synthetic APS-workers are more dependent on a specific context and relatively focused on the local scale. This again further differentiates analytical high-tech workers' residential location preferences from symbolic and synthetic APS-workers: the latter have a higher preference for living in central areas offering more opportunities for interactions than the former. Furthermore, compared to synthetic high-tech workers, analytical high-tech workers prefer a 'people climate' to a larger extent, since larger regions function as nodes in international research communities. Overall, although analytical high-tech workers are less urban-oriented compared to synthetic and symbolic APS-workers, they are less suburban-oriented compared to synthetic high-tech workers.

Although both synthetic and symbolic APS-workers prefer central areas, underlying motivation differs: one for time/cost minimization; the other for inspiration

Although both symbolic and synthetic APS-workers' residences locate in central areas, the underlying mechanism and their own targeted utility might be different. Synthetic knowledge creation combines existing knowledge to solve a practical problem. Synthetic APS-workers who frequently engage in practice-oriented working mode might pay much attention to discernable or tangible benefits in their residential choices. Since face-to-face interactions allow more in-depth and fast feedback than any other forms of communication, synthetic APS-workers select central areas (with an averagely shorter distance to current and potential connections) that facilitate frequent face-to-face communications with their customers efficiently. This is confirmed by the finding that among all groups of knowledge workers, only the group of synthetic APS-workers who are single parents, with very limited time budget, have the largest likelihood of residing in central areas compared to other life-cycle stages. In contrast, symbolic APS-workers with the heuristic mode of knowledge creation regard their daily lives per se as valuable opportunities for interpreting and creating cultural meanings, thus accumulating diverse experiences and enlarging their creative capacity. They also value many intangible aspects in their considerations, such as the attractiveness, the social and cultural mixture, and the vitality of the neighborhood. Symbolic APS-workers choose central areas as residential locations, which is mainly driven by the inspiring ‘bohemian’ atmosphere there (Florida 2002b).

Various demands of housing ownership (associated with knowledge base) have different spatial implications

Furthermore, various demands for housing ownership also influences residential location. Different efforts that individuals devote to improving certain attributes in their searches suggest that individuals might form hierarchical considerations of certain attributes when selecting a residence. The housing tenure and dwelling size are the first considerations, followed by the commute time and commute distance, while services and the surrounding environment belong to the last level of consideration. Since it is easier to realize housing ownership in more peripheral areas with lower land prices than central areas given a limited budget, different demands for housing ownership among each group of knowledge workers also contributes to different spatial processes. To interpret the different demands for housing ownership between the group of synthetic high-tech workers and synthetic APS-workers, and the group of symbolic APS-workers and analytical high-tech workers, it may be useful to relate it to the characteristics of knowledge economic sectors. Economic sectors based on analytical or symbolic knowledge bases are relatively less path-dependent compared to those drawing mainly on synthetic knowledge (Asheim and Hansen 2009: 431). Different path dependency and attitude towards diversity of the economic sectors might even influence the degree of conservative attitudes of individual workers. Since housing ownership frequently equates to a low degree of mobility or a high level of stability, knowledge workers mainly using synthetic knowledge tend to have a larger demand for housing ownership compared to knowledge workers using mainly analytical or symbolic knowledge.

Different forces altogether result in various spatial processes

It is noticeable that there is a general de-concentration process of residential locations, which is associated with the fact that inappropriate dwelling size is frequently mentioned as the motivation for moving. Nevertheless, the de-concentration process varies, since the underlying motivations and preferences generate different forces: among symbolic APS-workers, the preference for central-areas largely offsets the dispersion force resulting from increasing the dwelling size. In contrast, there are only dispersion forces (e.g., demand for larger dwelling size and low-density residential environment) among synthetic high-tech workers’ residential locations. Among analytical high-tech workers and synthetic APS-workers, the mode of knowledge creation generates offsetting forces regarding the concentration or de-concentration process. Hence, the final spatial outcome of their residential locations lie in between those of symbolic APS-workers and synthetic high-tech workers.

9.2 The role of commute in residential trade-offs of knowledge workers

Commute as a lubricant among synthetic high-tech workers; whereas demand for job-housing proximity renders the commute a constraint among symbolic APS-workers

On the one hand, knowledge workers do not limit their job search to a geographically focused area and will expand the spatial extent to search for jobs with better prospects. On the other hand, knowledge workers also consider an acceptable/reasonable job-housing distance. Different groups of knowledge workers position themselves differently regarding these two aspects. That is, each group of knowledge workers attach different weights to job-housing proximity, and commute trip plays different roles in their spatially-related choices. A long commute distance as well as an increase of in commute distance after a joint change of residence and workplace are a feature of synthetic high-tech workers' larger tolerance of commute distance. Commute functions as a lubricant for synthetic high-tech workers to achieve a better job as well as a better residence, within a reasonable time and cost budget. As mentioned previously, synthetic high-tech workers are more willing to pay for other attributes, such as the housing ownership and dwelling size in their residential choice. In contrast, results suggest that the housing-job proximity is an essential part of the residential and job choice among other groups of knowledge workers (especially symbolic APS-workers). Commute functions in this case as a constraint. The realization of an improved housing-job proximity implies the compromises of residential costs in residential location choice. Following symbolic APS-workers but to a lesser extent regarding the demand for short commutes, synthetic APS-workers are also willing to pay for the job-housing proximity.

Spatial scale of the interaction network might also associate with commute tolerance

In addition, the spatial scale of the interaction network associated with each employment sector might also influence commute tolerance. For instance, symbolic and synthetic APS-workers frequently communicate with local partners due to the high dependency of context and the significance of frequent face-to-face interactions, thus tending to have a smaller tolerance for the commute trip. In contrast, analytical and synthetic high-tech workers' tolerance of an acceptable length of commute, given that they are frequently connected with potential partners beyond the local scale supported by ICT technology, is very likely to be enlarged to some extent.

9.3 Choice of commute transport mode among knowledge workers

Residence and workplace location both condition the choice of commute transport mode.

Since commute is the journey between the location of residence and workplace, the choice of commute mode is conditioned by the characteristics of these two locations. The different preferences for residential locations (associated with the knowledge base) illustrated in Chapter 6 conditions the travel environment of certain commute modes. In addition, results also demonstrate that the choice of commute mode is also influenced by the location of the workplace that is related to the knowledge type. The usage of symbolic knowledge and the output of meanings and cultural symbols within creative industries are generally located within inner urban areas. In contrast, the impact of analytical knowledge and the output of new products within high-tech industries are usually found in low-density suburban areas. Different location dynamics of knowledge-intensive firms as well as different location choices of individual knowledge workers condition the relative advantages (in terms of time and cost) of different travel modes, and thus their choice of commute modes.

The choice of commute transport mode bound up to a certain location not always reflects individual real mobility preferences

As indicated in the previous paragraph, the commute choice is more like an adaption to the location choice, which does not necessarily reflect the travel attitude. As Storper and Scott (2009) put it, “The urban environment, in short, offers a structured set of intertwined benefits and costs, and as a result, the preferential selection of certain subsets means that we automatically gain others, whether we want them or not” (Storper and Scott 2009: 162). In addition, Myers and Gearin (2001) notice that residents in large-lot dwelling in suburban areas still express their wish for driving less in a survey, although a driving lifestyle is bound up in the revealed preference for more space (Myers and Gearin 2001: 639). Similarly, the present study also finds that synthetic high-tech workers who commute to their workplaces with cars also regard the accessibility of public transport as important. Evidently, the observed travel behavior does not always represent the actual preference of the individual, which should be taken account of before deducing an individual’s mobility preference from their actual commute mode. Accordingly, combining with individual assessment of the importance regarding certain travel modes near residences or workplaces is necessary.

Knowledge workers have different attitudes towards certain travel modes, which corresponds to their orientation towards external environment (people and things)

Unlike the analysis of revealed preference based on the choice among many available residential alternatives, there is no information on the process of choosing modes among available alternatives. Hence, it is necessary to check the individually assessed importance of certain travel modes near the residence or workplace to understand individuals' real mobility preferences. Results indicate that there might be a linkage between knowledge base and the preference for certain commute mode. Results clearly demonstrate that a larger share of synthetic high-tech workers report greater preference for car-friendly environment compared to other groups of knowledge workers. For synthetic high-tech workers who engage in less frequent intentional and unintentional face-to-face interactions, the commute path using a car matches more with this detachment from communications with the external environment. In contrast, the commute contains more functions among symbolic APS-workers, analytical high-tech workers and synthetic APS-workers, since the associated knowledge creation is to some extent independent of a fixed workplace. Commute with public transport and active modes may provide opportunities for the relative subjective and relational interpretations of meanings and values of the surrounding environment and people during the process. That corresponds to the study that these three groups of knowledge workers frequently mentioned the importance of accessibility of public transport and active modes between their residence and workplace.

9.4 'Knowledge-base'-related revealed preference of residential location and commute transport mode

Knowledge base is more relevant to the spatial choice than employment sector

The difference between spatial choices among workers employed in high-tech industries and APS sectors is not apparent, whereas there are significant differences between the spatial choices among workers drawing on different types of knowledge base. This suggests that the knowledge base is more relevant related to their underlying rationale of the spatial choices than the employment sector. It also justifies the robustness of the research methodology that knowledge workers are also differentiated by the primary knowledge base they apply in jobs in parallel with the employment sector.

Results show that symbolic APS-workers have a greater preference for living in central areas and frequently commute with public transport or active modes, whereas synthetic high-tech workers show a greater preference for peripheral residential areas, and depend more on cars to reach their workplaces. This is consistent with the existing findings of other researchers. Musterd (2006) found that employees in creative sectors and in cultural and social sciences in higher education disproportionately live in central locations in Amsterdam (Musterd 2006). Florida (2002a) also noticed that a certain combination of amenities such as cafés, galleries and a tolerant and bohemian atmosphere are closely correlated with the presence and growth of a 'creative class' (Florida 2002a). Grabher (2001) confirmed that people working in advertising, media and design have a greater preference for urban living (Grabher 2001). Spencer (2015) found that workers in cultural and creative industries tend to live in inner urban areas (Spencer 2015). Asheim and Hansen (2009) found that workers who primarily use symbolic knowledge have a larger preference for a 'people climate' than a 'business climate' (Asheim and Hansen 2009). Moreover, this is also supported by the finding of Hafner, Heinritz, et al. (2008) that creative workers are more affine to the city of Munich and display an urban pattern in terms of their space utilization. The cultural diversity and the diversity of leisure and entertainment to some extent drive their location in the city (Hafner, Heinritz, et al. 2008: 87). In contrast, workers in science and technology industries tend to live in suburban areas (Spencer 2015). Occupational categories 'Technicians', 'technical qualified personnel', and 'health professionals' show a below-average concentration in agglomerations and urbanized areas, and also accumulate increasingly in areas of less density (Growe 2009). In addition, Darchen and Tremblay (2011) observed that a majority of students in science and technology would rather live in the suburbs after their graduation (Darchen and Tremblay 2011). Ilmonen's (2009) study showed that "Engineers want to have a peaceful environment and are conservative and family oriented, while artists and designers are more bohemian and want to live where the "buzz" is" (Asheim and Hansen 2009: 432). Nevertheless, there are no consistent findings on the location preferences among synthetic APS-workers and analytical high-tech workers. Synthetic APS-workers also show a certain preference for peripheral areas, as long as they offer good accessibility to public transport. Analytical high-tech workers show a larger preference for active modes, even though they prefer living in peripheral locations. These inconsistencies are also reflected in previous findings. On the one hand, those working in financial sectors and ÍCT sectors are more often found in suburban locations (Musterd 2006). On the other hand, occupations such as banker, insurance salesman, and 'Lawyer, legal advisors' have an affinity to agglomeration core cities.

Robust findings: 'Bohemian' symbolic APS-workers and 'conservative' synthetic high-tech workers represent two poles of spatially-related preference; analytical high-tech workers and synthetic APS-workers are positioned in between as intermediate groups

Moreover, 65% of all ICT employees indicate a preference for living within a reach of city center (van Oort, Weterings and Verlinde 2003), which could be substituted by a shopping center nearby. Asheim and Hansen (2009) also noticed that workers using analytical knowledge have a larger preference for a 'people climate' compared to workers using synthetic knowledge, while having a smaller preference compared to symbolic APS-workers (Asheim and Hansen 2009).

In parallel with the employment sector, Knowledge typology associated with sensitivity to spatial distance, communication to local environment, as well as path dependency, influences residential location and commute mode choice

Results suggest that the spatial implications of the interaction networks associated with each type not only applies to knowledge-intensive firms but also to individual knowledge workers, since they are the basic units for exchanging and creating knowledge (Table 17). Firstly, job location conditions the basic reference point for residential location and basic transport infrastructures (e.g. public transport accessibility, car parking availability) that directly influence the commute mode choice. Apart from the influence from the location of knowledge-intensive firms, the final residential location of knowledge workers depends also on the sensitivity to the geographical separation, the knowledge production mode, as well as the path-dependency associated with a certain knowledge base.

Table 17. 'Knowledge-base'-related factors that influence the residential location choice among knowledge workers.

Dimensions of influences on residential location choice		Symbolic APS-workers	Synthetic APS-workers	Analytical high-tech workers	Synthetic high-tech workers
Employment sector		Central-areas oriented	Central-areas oriented	Central-areas disoriented	Peripheral locations Specialization-oriented
Knowledge typology	Sensitivity to the spatial distance	Strong spatial sensitivity	Medium spatial sensitivity	Weak spatial sensitivity	Medium spatial sensitivity
	Communication to local environment	Orient to local environment	Rather orient to local environment	Rather dis-orient to local environment	Beyond local environment
	Path-dependency, Openness to variety and creativity	Diversity-oriented, less path dependency	*Not available*	Radical innovation, not path dependent	Path-dependent; specific and measurement improvement

Underlying rationale of symbolic APS-workers' spatially-related choice

Symbolic APS-workers' stronger preference for urbanity can be attributed to centrally-located creative industries, strong spatial sensitivity, and their openness to frequent communications and exchanges with the local external environment associated with symbolic knowledge creation. As Spencer (2015) summarized, the clustering of creative industry firms together with the short distances to the residences of creative workers indicates that the action space or activity spaces of these creative workers will have a high degree of overlap with each other for a larger amount of time (Spencer 2015: 888). Hence, symbolic APS-workers tend to locate in high-density urban locations and commute with public transport or active modes. They are willing to trade off the residential costs for this urban-oriented lifestyle and job-housing proximity.

Underlying rationale of synthetic high-tech workers' spatially-related choice

In contrast, synthetic high-tech workers show a stronger preference for suburban locations due to the suburban locations of high-tech industries, their insensitiveness to spatial separation, and the relatively path-dependent and beyond local-scale knowledge exchanges associated with synthetic knowledge creation in high-tech industries. Synthetic high-tech workers are relatively 'footloose' regarding their residential location. Housing ownership, and dwelling size and quality are the main considerations in their residential choices. They are willing to tolerate a long commute and predominantly choose cars as the commute mode, which guarantees them a reasonable commute time as well as detachment from dense communications with the external environment.

Underlying rationale of Synthetic APS-workers' spatially-related choice

Whereas symbolic APS-workers and synthetic high-tech workers show clearly distinct spatially-related choices, synthetic APS-workers and analytical high-tech workers' spatially-related preferences are less extreme due to various factors generating offsetting forces. APS firms are more likely to be located in central areas since the communications with local customers are relatively frequent. This is a pull force for the residential location of synthetic APS-workers oriented towards central areas. However, synthetic knowledge is partially codified and the sensitivity towards geographical separation lies in between symbolic and analytical knowledge. In addition, industries based on synthetic knowledge are relatively path-dependent. Accordingly, synthetic APS-workers do not present an apparent location preference or choice within central areas, but to some extent orient themselves positively towards central and dense locations. Moreover, a peripheral location with good accessibility to public transport is also acceptable among these workers.

Underlying rationale of analytical high-tech workers' spatially-related choice

In contrast, science-based industries are frequently located in low-density suburban areas. In addition, analytical knowledge is the least sensitive to geographical distance, and the relatively lower demand of direct face-to-face interactions locally encourages analytical high-tech workers to enlarge their spatial extent in housing searches. These all generate forces to push their residential locations towards the suburban areas. Nevertheless, science-based industries and workers are innovation-oriented, which are more open to diversity in absorbing external or global knowledge sources. Large cities functioning as the node of science communities in exchanging knowledge are also attractive for them(Asheim and Hansen 2009). Overall, analytical high-tech workers' location preferences are similar to synthetic high-tech workers, but not as extreme as synthetic high-tech workers are. Despite the fact that both synthetic high-tech workers and analytical high-tech workers' spatially-related choices are influenced by factors that discourage them from locating in central areas, the impact of spatial insensitivity of analytical knowledge is less strong compared to the impact of the path-dependency of economic sectors using synthetic knowledge. This is because housing ownership is much more difficult to realize in central areas than peripheral areas in the metropolitan region of Munich with its extremely tight housing market. In addition, the knowledge base also connects with the commute mode choice. Analytical thinking is less convergent and more independent of a fixed workplace compared to synthetic knowledge creation. Hence, analytical high-tech workers prefer to commute with cycling or walking, thus engaging themselves in more communication with the surrounding environment, which might be complementary to analytical thinking. This resonates with Florida's (2002b) view that "the world is unfolding around you" during cycling or walking (Florida 2002b: 180), when analytical high-tech workers also make full use of the commute time to be inspired by people and events.

The impact of knowledge base needs to be weighed against conventional socio-demographical factors

Knowledge workers not only play the role of basic unit in creating knowledge, they also belong to members of households. The size, composition of household, and the stage in life-cycle may directly influence the amount of space needed and the importance of locational attributes in their residential choice (Beamish, Carucci Goss and Emmel 2001). From the spatially-related preference to the final choice, there is a filter of conventional socio-economic factors constituting the conditioning framework for decision-making. This corresponds to the finding that well-studied socio-demographic factors explain a large part of the total variance of location choice. In some cases, the location preference has to be traded off for the affordability or an adaption to another life-cycle stage. Results clearly show that symbolic APS-workers with a monthly household income less than 2000 Euros have to accept a residence outside of central areas, in a tight housing market like Munich. During a survey conducted by European Commission (2016), a minimal share (only 3%) of the interviewees agreed that it is possible to find reasonable accommodation at a reasonable price in Munich (European

Commission 2016: 26). Moreover, it is also noticeable that synthetic high-tech workers in two-person households have to compromise with the other household member, who might have different or even contrasting preferences (Oostendorp 2014). Similarly, the unstable preferences for better access over dwelling size among different population profiles again suggests that demographic composition and income distribution have a large influence on residential location. In addition, it is revealed that household type (size and life-cycle stage) might play a more dominant role than the income level in influencing residential location choice.

The impact of knowledge base needs to be weighed against the conditioning impact of spatial structure

It is also noteworthy that individual choice is always to some extent constrained by the given spatial built environment, namely the land use zoning system. This aspect cannot be ignored in the analysis of individual spatially-related choice. In some cases, individual preferences might be suppressed by the spatial conditioning framework and cannot be revealed via observation. Accordingly, the relatively long commute of high-tech knowledge workers does not equate to their devaluation of housing-job spatial proximity. Instead, it is more likely a response or adaption to the given residence and workplace. **Synthetic high-tech workers** also prefer residences that are in close proximity to job opportunities, namely areas with high-level science industry employment. However, living and working space do not have as much overlap as creative industries, since different types of land uses in suburban areas of these city regions are strictly separated on the one hand and space-intensive high-tech industries are distributed more dispersedly. Furthermore, this study contributes to the long-standing debate between the impact of residential self-selection and the structure effect of the built environment on the choice of commute mode (Naess 2014b; van Wee and Boarnet 2014; Naess 2014a). Results admit the impact of both built environment and residential self-selection. When comparing the attitude towards certain travel modes with the impact of the built environment on the choice of commute mode, the structural built environment is stronger, since the workplace's association is largest. Even semi-longitudinal analysis supports the dominant role of workplace location. However, if the residential self-selection is further included, residential location is also attributable to some extent to the attitude to certain modes of transport. Accordingly, the structural impact represented by the workplace location will reduce in significance, when comparing with the self-selection impact represented by the mobility preference together with the travel attitude induced residential location.

Nevertheless, after controlling for the abovementioned socio-demographic and spatial structural factors in the analysis, the parameter of knowledge base still contributes further to the total variances in the choice of residential location and commute mode. This indicates that knowledge base does generate independent influences in parallel with those aforementioned well-studied factors.

10 Conclusions

This chapter will firstly summarize the results and discussion that are closely related to the research hypotheses. Following this, some extended general learnings will be mentioned. This chapter will end by discussing the major limitations of the study and possible in-depth analyses in the future outlook.

10.1 (Partially) verified hypotheses

10.1.1 Integrity between interaction type of knowledge workers and their habitat environment

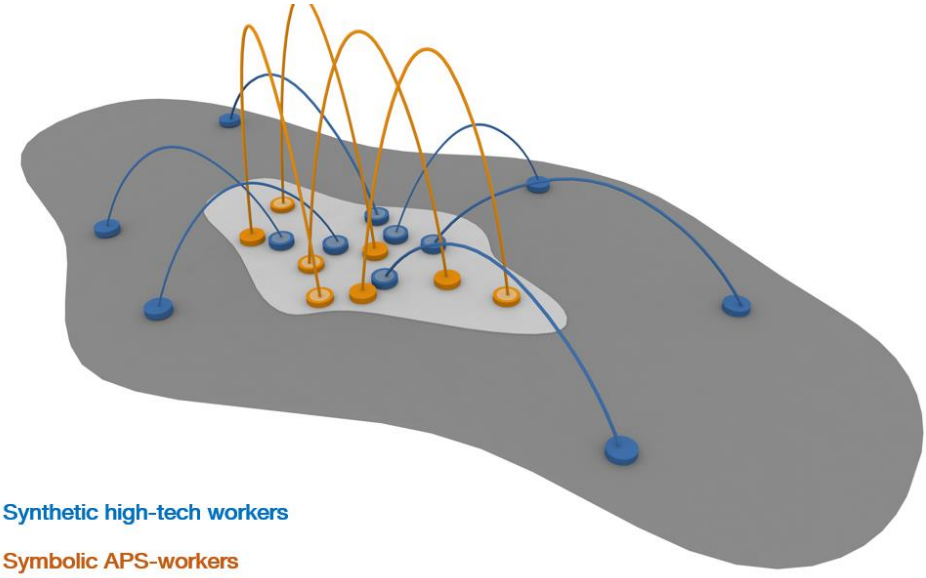


Figure 121. Sketch of interaction patterns among synthetic high-tech workers and symbolic APS-workers.

Firstly, the way individual knowledge workers tentatively use or select space reflects their underlying orientation or attitudes to encountering or interacting with other individuals (Thierstein 2016: 14). When making spatially-related choices, individuals are actually choosing a certain milieu, including physical and social environment, to adapt to their interaction types (Kalisch 2014: 60). This study approaches the issue from the perspective of knowledge base to explain their varying demands for encounters with other people. The influence of knowledge base, knowledge production mode and the embedded context in relation to the organization on spatial patterns not only applies to knowledge-intensive firms but also knowledge workers, since knowledge workers are the basic units for exchanging and creating knowledge that firms require. The different sensitivities to distance of each knowledge base are associated with individual worker's preference for spatial proximity. Different modes of knowledge production together with different contexts in relation to the organization will affect knowledge workers' orientation towards the communications with the local external environment. Thus, knowledge workers using different types of knowledge bases have distinct locational preferences and make corresponding spatially-related choices. Specifically, the characteristic of knowledge production mode is consistent with the spatial features of residence location, workplace location, as well as commute path. Knowledge workers with algorithmic knowledge production mode and convergent thinking follow some relatively predictable patterns. They are able to reach their final decision-making by estimating and optimizing the overall utilities of the apparent attributes such as size, cost and so on. Peripheral residential areas with lower residential cost and larger dwelling size are therefore preferred. In contrast, knowledge workers with heuristic knowledge production mode and divergent thinking are lifestyle or experience oriented. They are open to experience and flexible in thought, and are relatively more likely to orient to the surrounding environment or world. Their daily lives per se (living, working, as well as commute) are an essential channel for them to receive the inspiration that their job requires. In their decision-making process, many subjective assessments and intangible effects (such as the consideration of the atmosphere) are also included. Correspondingly, dense, heterogeneous, central areas are the optimal spaces for them (Figure 121). In addition, commuting has also been integrated into the job-housing matrix. Housing, job and mobility are integrated considerations for the individual actor, and not merely functionally categorized into separate spheres. Therefore, the 'atmosphere' or the social environment surrounding residence, workplace and along the commuting path are similar in type in terms of the density, mixture, as well as the connection to the local environment. Individuals with a preference for heterogeneous spatial locations also tend to orient themselves towards the external environment during their commute trips. In contrast, individuals with a preference for relatively homogenous spatial locations tend to remain in relatively detached environments for their commutes.

10.1.2 Different residential location preferences and choices among subgroups of knowledge workers

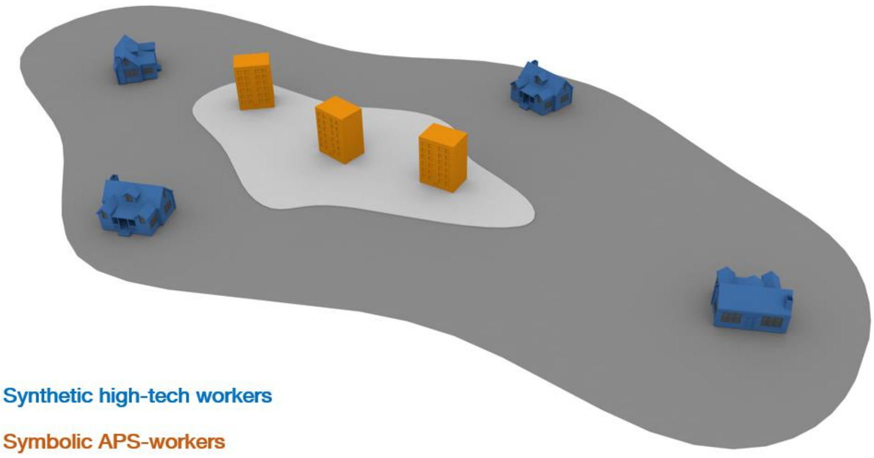


Figure 122. Sketch of residential location among synthetic high-tech workers and symbolic APS workers.

The more frequently symbolic knowledge is applied in the job, the more frequently heuristic knowledge production is practiced and the more interactions are embedded within inter-organizational contexts. Symbolic APS-workers desire or attach more value to dense, mixed and urban spaces, which is consistent with their importance assessment of corresponding attributes as well as their frequent participation in cultural and leisure activities. In contrast, synthetic high-tech workers present opposite spatially-related preferences and choices. They are more attracted by larger dwellings within low-density suburban areas. The first conclusion is that symbolic APS-workers tend to concentrate their residences in space, whereas synthetic and analytical high-tech workers tend to deconcentrate their residences in space (Figure 122). However, synthetic APS-workers also show a certain preference for central areas, while peripheral areas may be chosen as residence, as long as they offer the accessibility of public transport.

10.1.3 Different trade-offs in residential location choice among subgroups of knowledge workers

As mentioned in the last section, preferences will continuously motivate people to realize them in the trade-off process. To realize a residence within central locations with short commutes, adequate services, various mobility options, symbolic APS-workers have either to reduce dwelling size and/or pay more for each square meter. Paying more is more frequently chosen than reducing the size, since the latter is less elastic compared to the cost assignment. In contrast, when a central location is not the first priority criterion that synthetic high-tech workers must consider, a comfortable large dwelling with good amenities and facilities, or a purchased residence becomes the objective of residential choice. In this case, a long commute distance accompanied with a larger mobility cost is accepted. The second conclusion is that symbolic and synthetic APS-workers trade off housing costs for short commutes, whereas synthetic high-tech workers tolerate long commutes for larger dwellings or housing ownership. Analytical high-tech workers are also willing to sacrifice residential costs for shot commutes.

10.1.4 Different commute transport modes among subgroups of knowledge workers

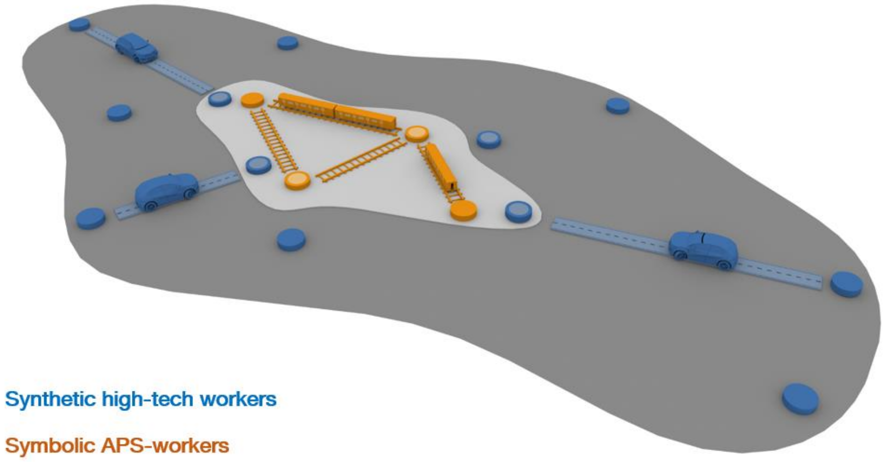


Figure 123. Sketch of choice of commute transport mode among synthetic high-tech workers and symbolic APS worker.

The choice of commute mode can be mainly attributed to two aspects. Firstly, the choice of commute mode is a trade-off between the commute distance and commute time (which does not vary much within a region), long commute distances accepted by synthetic high-tech workers will lead to the dependence on faster transport mode like cars, whereas short commute distances preferred by symbolic APS-workers tend to allow them to choose from various alternatives. This will in turn encourage them to choose the slower transport mode that brings more benefits in other respects. Secondly, knowledge workers also consider the features along the commute path associated with the commute mode in their considerations. Travelling with public transport intentionally and unintentionally involves them in more interactions with surrounding people, whereas travelling with active modes involves fewer interactions with surrounding people but more with the surrounding environment. Travelling by car is relatively detached from the surrounding environment as well as people. The attitude towards a certain commute mode also plays a key role in selecting the commute mode apart from the conditioning framework, namely the location of residence and workplace, as well as the commute distance. The third conclusion is that symbolic APS-workers, synthetic APS-workers and analytical high-tech workers frequently use public transport or active modes to commute, whereas synthetic high-tech workers depend more on cars to reach their workplaces (Figure 123).

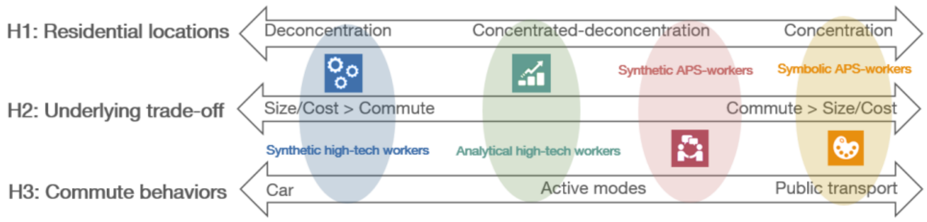


Figure 124. Continuum of spatially-related preferences and choices among each group of knowledge workers.

Spatially-related preference continuum rather than a binary division

Overall, the conclusion is that the preference for spatial proximity and central locations is distributed along a continuum rather than the binary division in the hypothesis (Figure 124). Symbolic APS-workers represent one pole of the continuum: these workers disproportionally live in central areas and frequently use public transport or active modes to commute, and trade off residential costs for short commutes. In contrast, synthetic high-tech workers represent the other pole of the continuum: these workers disproportionally reside in peripheral areas and depend more on cars to reach their workplaces, and they are willing to tolerant long commutes to realize a better dwelling or a purchased residence. Synthetic APS-workers and analytical high-tech workers belong to intermediate groups: they lie in between the two poles of apparent preferences: namely the spatially-bound group (symbolic APS-workers) and spatially-unbound group (synthetic high-tech workers). In addition, the intermediate groups also differ from each other: synthetic APS-workers are more similar to symbolic APS-workers, whereas analytical high-tech workers are more analogous to synthetic high-tech workers.

10.2 General learnings

Apart from verifying the research hypotheses, four relevant issues have been illuminated in the study and will be discussed in the following section.

10.2.1 Interdependency between the choice of residence, workplace and commute among knowledge workers

The choice of residence, workplace and commute transport mode are indeed interrelated among knowledge workers: firstly, job location conditions and residential location via the commute distance. Even people who do not necessarily locate their residences and workplaces adjacently keep the relative location of current and potential jobs in mind. Since there is a dense concentration of APS firms in the inner urban areas, residing in central areas better guarantees a shorter commute distance now or in the near future for knowledge workers in the APS sectors. In contrast, high-tech industries are relatively dispersed in space, and especially those in the developed stages are likely to be located further from the city center, which results in a choice of peripheral locations among synthetic high-tech workers. Overall, the residential locations of knowledge workers to some extent match with the sites of knowledge-intensive firms. In addition, the location of residence and workplace together influence the choice of travel mode to commute: The preference for certain location influences both specific travel accessibility at the residence and workplace, as well as the spatial proximity between residence and workplace, which in turn influences the choice of commute mode. Lastly, the preference for a certain travel mode also influences the residential location. Symbolic APS-workers with car-disinclination will 'restrict' themselves to central areas, whereas synthetic high-tech workers with a preference for cars also 'constrain' themselves to some extent to low-density peripheral areas.

10.2.2 The perspective of knowledge base is also important in parallel with (beyond) the employment sector

Regarding the residential choice within a region, individual knowledge workers will pay attention to many other specific location factors beyond job prospects. Urban planning and policy-making should take into account these spatially-related demands and preferences. This would very probably improve knowledge workers' satisfaction levels in respect of these fundamental aspects and thus contribute to the localization of knowledge agents and subsequent knowledge spillovers. Results clearly confirm that the city is actually becoming segregated when observed at the level of neighborhood. That is, each group of talents differentiated by knowledge typology actually tend to inhabit certain micro-environments matching their rhythm of production and consumption. Income, household size, as well as the employment sector are not sufficient to differentiate individual knowledge workers. Instead, the particular knowledge base used to perform their actual job-related tasks should be also included as one of the essential parameters.

In addition, the perception of functional region would also benefit from some changes and adaptations. Functional region refers to an area within which a large proportion of the population and industry resides within a boundary (Kropp and Schwengler 2014: 2). Regarding the increasing commute distance among knowledge workers, the spatial boundaries of functional regions when studying knowledge economies should also be dynamically revised. Additionally, due to the different commute tolerances among each group of knowledge workers, the definition of functional region should also be differentiated according to primary knowledge base as well as the type of employment.

10.2.3 Revealed preference approach detects individual prime residential preference

Analyzing the attributes of residence alternatives that knowledge workers view and the residence that they currently live in could reveal that they differ in some respects. For instance, synthetic high-tech workers also view residences in central locations. However, this preference is not that strong compared to the preference for large dwellings. The final decision to give up the location within the city of Munich implies that they are more willing to pay for their prime preference (e.g., lower residential unit cost or the dwelling size). Symbolic APS-workers also viewed residences with longer commutes and cheaper residential unit cost or larger dwelling size, but eventually ended up with a smaller commute, which is their priority preference. This again verifies the differences between the stated preference and revealed preference given a budget constraint.

10.2.4 Justify as well as facilitate spatial planning

Among knowledge workers, both urbanites and suburbanites coexist. The forces of urban concentration and dispersion are simultaneously observed. Since "The physical results of people's past preferences for housing last longer than do the people themselves" (Storper and Manville 2006: 1267), the physical results of people's current preferences for housing will last longer and might give a clue as to future spatial patterns. To summarize, since spatial structure can be considered as the materialized form of the aggregated individual choices along the time axis, this research could bridge the gap between individual decision-making and spatial planning strategy.

Justify the significance of location attributes in shaping spatially-related choices, especially travel behaviors

Firstly, even though the self-selection effect is considered, the role from the workplace and residence still generate dominant effects on the travel behaviors. This again justifies improving the spatial structure, which would generate a positive impact on shifting the commute mode choice, thus bolstering the meaning and contribution of urban planning in sustainable development. Secondly, the above results and discussion clearly demonstrate that individual residential choices are sensitive to the functional environment rather than the administrative unit. Urban planning and policy makers should put more emphasis on integrated planning that cuts across the administrative delimitations of the areas in a region.

Latent preference closely associated with satisfaction should also be addressed

In addition, the aforementioned latent preferences of knowledge workers should also be addressed, since they are associated closely with their dissatisfaction with their living situation. To better attract and retain knowledge workers calls for more endeavors devoted to helping them to realize their latent preferences. As mentioned previously, although some synthetic high-tech workers commute with cars to reach their workplaces, they still value access to public transport. This suggests that spatial planning should target improving the accessibility of suburban residential locations, which might help in encouraging individuals to abandon cars and shift to using public transport to commute.

Urban spaces that encourage face-to-face interactions should be guaranteed in the planning

Overall, the study confirms the synergy effect of the concentration of talented individuals in cities. Cities as important spatial entities facilitate the interactions of knowledge agents, including knowledge workers both in the same field as well as among different fields. Network effects increase in an exponential manner with the increase of knowledge worker population. In summary, this study offers additional evidences for the statement of Storper and Venables (2004) that the key function afforded by the ever increasing importance of face-to-face interaction underlies the clustering of knowledge workers and urban re-concentration (Storper and Venables 2004: 353). Hence, more public space oriented towards creating more interaction opportunities in cites should be another emphasis in urban planning.

10.3 Limitations and outlook

In the very last section of the conclusion, the major limitations of this study will be addressed. Based on these limitations, future in-depth analyses that might improve and/or build on the present study will be introduced.

Combining with qualitative interviews to better understand the decision-making process and verify unobservable motivations

Results are correlation based, suggest tendencies in the residential, and commute mode choice, instead of establishing actual causality in reality. A qualitative method combined based on the following three considerations is advisable. Firstly, interviews allow the tracing of detailed decision-making processes. This could address the issue of the interference of individual irrational choices in detecting preferences. Since the study deals with people's preference and choices, many uncertain factors might bias the evaluation and assessments. For instance, respondents might underestimate the transportation costs when they choose a location in the suburban area, in most cases people might simply be attracted or to some extent 'induced' by the cheap housing price and the apparent savings on the residence. However, the transportation cost associated with a residence within the suburban area as a long-term issue might be overlooked. As Storper and Manville (2006) put it, "Humans sometimes have difficulty in forming rational anticipations and if a second-order preference has distant benefits and immediate costs, while a competing option has immediate benefits and distant costs, then the competing option is likely to prevail" (Storper and Manville 2006: 1264). Living in the suburban areas in this situation does not entail their preference or demand for accessibility, since it is undermined by their underestimation of the costs associated with the commute and accessing other activities. Secondly, revealed preference might not be stable, since it might involve a hidden component of dissatisfaction. This problem is even more serious in the Munich region, where the housing market is extremely tight and people have to make a decision among quite limited available offers. Hence, the choice of current residence might result in various degrees of dissatisfaction. Qualitative interviews could also collect the information on the satisfaction of the current decision and their intention to realize the latent preference in the future. This could help to verify the prime residential preference as well as differentiate the relative importance of the latent preference. Thirdly, analyzing the web-survey alone makes it difficult to tell whether the shift of the commute mode is owing to the change of spatial structure near the residence or rather actually owing to their latent preference for a certain travel mode. Qualitative interviews could drill down to gain more information on this issue, thus discovering those relations that are closer to the causal influences at the level of the individual. Overall, combining this study with qualitative interviews could help to construct a more comprehensive causal or correlation framework, beyond those correlations investigated here.

Further include other relevant factors to better understand the complex issue of residential choice

Spatially-related behavior is a complex phenomenon resulting from many underlying factors. Many other factors also playing significant roles in the decision-making process are not included in the analysis. Future study should orient to collecting information on two important aspects: factors related to the individual decision-maker and factors related to the individual dwelling. The following factors related to the individual decision-maker should be further considered. Firstly, it is related to other household members, since the household is the unit of decision-making in residential choice. However, there is no information regarding the workplace location of the other (employed) members of the household, thus the additional effect of the compromises between household members with different preferences is not examined in the current analysis. Secondly, the residential choice might also relate to (personal) social networks, such as proximity to parents and relatives. Collecting information on the networks of their interactions, which transcend their residential space, could help investigate whether the residential choice is to some extent in accordance with the form of networks at the firm level. Thirdly, the personality of the individual also influences the residential trade-offs. In addition, it is important to integrate factors related to the individual dwelling in the analysis. Firstly, information on the accessibility of green areas as public spaces is not included here, which might bias the deduction of the preference for certain attributes. Secondly, information such as the age of housing, the orientation of the dwelling, as well as the attractiveness of the neighborhood influencing the residential unit cost should be also collected, since they are also important factors in residential choice and might even surpass the influence of location attributes. Thirdly, the research scope of residence, workplace and commute does not describe a comprehensive picture of individuals' daily life. The preference and choice of residence might not always correspond to the workplace and the mode of commute, but is also related to their spatial patterns of cultural and leisure activities. Further research could also benefit from collecting the spatial distribution of these cultural and leisure activities.

Continuing check the relative importance of built environment and mobility preference in the choice of commute transport mode

While this study admits that residential self-selection effect and built environment are both essential in influencing the choice of commute transport mode, it does not further investigate the relative magnitude of these two factors on the choice of commute mode. Future research should also take the parking availability at the workplace into account, since it also significantly affects the transport accessibility. Integrating all relevant factors from both two aspects would contribute to the objective assessment of their role in constituting and shaping individual mobility behavior. Additionally, It is assumed that the individual who shifts immediately from using cars to public transport after moving residence from suburban areas to central areas very likely has distinctly different underlying attitudinal motivations to someone who adjusts their commute behavior after residing in the new residential location for several months. It is also worth recording the specific time point that a shift in the commute mode after residential move or change of job location occurs to better understand the role of mobility preference and the spatial structure in shaping individual preference and actual choice in reality.

As mentioned in the categorization of knowledge workers, each individual knowledge worker actually employs more than one knowledge base in performing their activities in jobs. Furthermore, the major source of knowledge also differs in the stages of innovation (radical innovator, incremental innovator, and adapters). Accordingly, the influence of the integration of different knowledge bases and the change of the dominant knowledge bases within one individual on the residential location and commute choice would benefit from in-depth analysis.

Further investigate the impact of integrating more than one knowledge base on spatially-related choices of knowledge workers

APPDENDICES

A. Questions to filter knowledge workers in web-survey

Question 1. Zu welchem Berufssektor zählt Ihre Haupterwerbstätigkeit? (Wählen Sie zunächst die allgemeine Bezeichnung und dann die genaue Bezeichnung) [Source: (Thierstein et al. 2016)].

Bei „Produktions- und Handwerksberufe“	☐ Land-, Forst- und Gartenbauberufe ☐ Fertigungsberufe (Rohstoff, Glas, Kunststoffe, Holz, Papier, Metall, Textil und Leder) ☐ Produktdesign und kunsthandwerkliche Berufe, bildende Kunst, Musikinstrumentenbau ☐ Feinoptik-Produktionsberufe ☐ Maschinen- und Fahrzeugtechnikberufe ☐ Mechatronik-, Energie- und Elektroberufe ☐ Technische Forschungs-, Entwicklungs-, Konstruktions- u. Produktionssteuerungsberufe ☐ Bauplanungs-, Architektur- und Vermessungsberufe ☐ Hoch- und Tiefbauberufe, (Innen-)Ausbauberufe ☐ Gebäude- und versorgungstechnische Berufe ☐ Lebensmittelherstellungsberufe
Bei „Personenbezogene Dienstleistungsberufe“	☐ Tourismus-, Hotel- und Gaststättenberufe ☐ Medizinische Gesundheitsberufe ☐ Berufe in der Medizin-, Orthopädie- und Rehatechnik ☐ Andere nicht-medizinische Gesundheitsberufe ☐ Erziehung, soziale und hauswirtschaftliche Berufe ☐ Lehrende und ausbildende Berufe ☐ Geisteswissenschaftliche Berufe (sprach-, literatur-, geistes-, gesellschafts- und wirtschaftswissenschaftliche Berufe) ☐ Darstellende und unterhaltende Berufe
Bei „Kaufmännische und unternehmensbezogene Dienstleistungsberufe“	☐ Handelsberufe ☐ Berufe in Unternehmensführung und –organisation ☐ Berufe in Versicherungs- und Finanzdienstleistungen, Rechnungswesen und Steuerberatung, ☐ Berufe in Recht und Verwaltung ☐ Berufe in Werbung, Marketing, kaufmännischen und redaktionellen Medien
Bei „IT und naturwissenschaftliche Dienstleistungsberufe“	☐ Mathematik-, Biologie-, Chemie- und Physikberufe ☐ Geologie-, Geografie- und Umweltschutzberufe ☐ Informatik-, Informations- und Kommunikationstechnologieberufe
Bei „Sonstige wirtschaftliche Dienstleistungsberufe“	☐ Technischer Betrieb des Eisenbahn-, Luft- und Schiffsverkehrs ☐ Fahrzeugführung im Eisenbahn-, Luft- und Schiffsverkehr ☐ Andere Verkehrs- und Logistikberufe ☐ Reinigungsberufe ☐ Sicherheitsberufe

Question 2: Welche berufliche Stellung haben Sie in Ihrer Haupterwerbstätigkeit? (Bitte wählen Sie die Option, die am ehesten auf Sie zutrifft) [Source: (Thierstein et al. 2016)].

☐ Selbstständig im Handel, im Gewerbe, im Handwerk, in der Industrie, im Dienstleistungssektor, auch Ich-AG

☐ Beamter/Beamtin, Richter/-in, Berufssoldat/-in

☐ Angestellte/r

☐ Arbeiter/-in

☐ Akademiker/-in in freiem Beruf (Arzt/Ärztin, Rechtsanwalt/-anwältin, Steuerberater/-in u. Ä.)

☐ Selbstständige/r Landwirt/-in bzw. Genossenschaftsbauer/-bäuerin

☐ Mithelfende/r Familienangehörige/r

☐ Keine Angabe

Bei „Selbstständig“ und „Akademiker/in“ in 0, **Frage 0.1: Wie viele Mitarbeitende haben Sie?**

☐ Keine weiteren Mitarbeiter/-innen

☐ Bis 4 Mitarbeiter/-innen

☐ 5 und mehr Mitarbeiter/-innen

☐ Keine Angabe

Bei „Beamter/Beamtin“ in 0, Frage 0.2: Welcher Laufbahngruppe gehören Sie an?

☐ Einfacher Dienst (bis einschl. Oberamtsmeister/-in)

☐ Mittlerer Dienst (von Assistent/-in bis einschl. Hauptsekretär/-in, Amtsinspektor/-in)

☐ Gehobener Dienst (von Inspektor/-in bis einschl. Oberamtsrat/-rätin)

☐ Höherer Dienst (von Rat/Rätin aufwärts), Richter/-in

☐ Keine Angabe

Bei „Angestellte/r“ in Frage 0, Frage 0.3: Bitte spezifizieren Sie die Art Ihrer wichtigsten Erwerbstätigkeit

☐ mit ausführender Tätigkeit nach allgemeiner Anweisung (z. B. Verkäufer/-in, Datentypist/-in, Sekretariatsassistent/-in, Pflegehelfer/-in)

☐ mit einer qualifizierten Tätigkeit nach Anweisung (z. B. Sachbearbeiter/-in, Buchhalter/-in, technische/r Zeichner/-in)

☐ mit eigenständiger Leistung in verantwortlicher Tätigkeit bzw. mit Fachverantwortung für Personal (z. B. wissenschaftliche/r Mitarbeiter/-in, Prokurist/-in, Abteilungsleiter/-in bzw. Meister/-in im Angestelltenverhältnis)

☐ mit umfassenden Führungsaufgaben und Entscheidungsbefugnissen (z. B. Direktor/-in, Geschäftsführer/-in, Mitglied des Vorstandes)

☐ Keine Angabe

Bei „Arbeiter/in“ in Frage 2, Frage 2.4: Bitte spezifizieren Sie die Art Ihrer wichtigsten Erwerbstätigkeit

☐ Ungelernt

☐ Angelernt

☐ Facharbeiter/-in ☐ Vorarbeiter/-in, Kolonnenführer/-in

☐ Meister/-in, Polier/-in

☐ Keine Angabe

B Other relevant figures

Figure 1A. Existing spatial-functional structure of the metropolitan region of Munich [Source:(Thierstein et al. 2016: 29)].

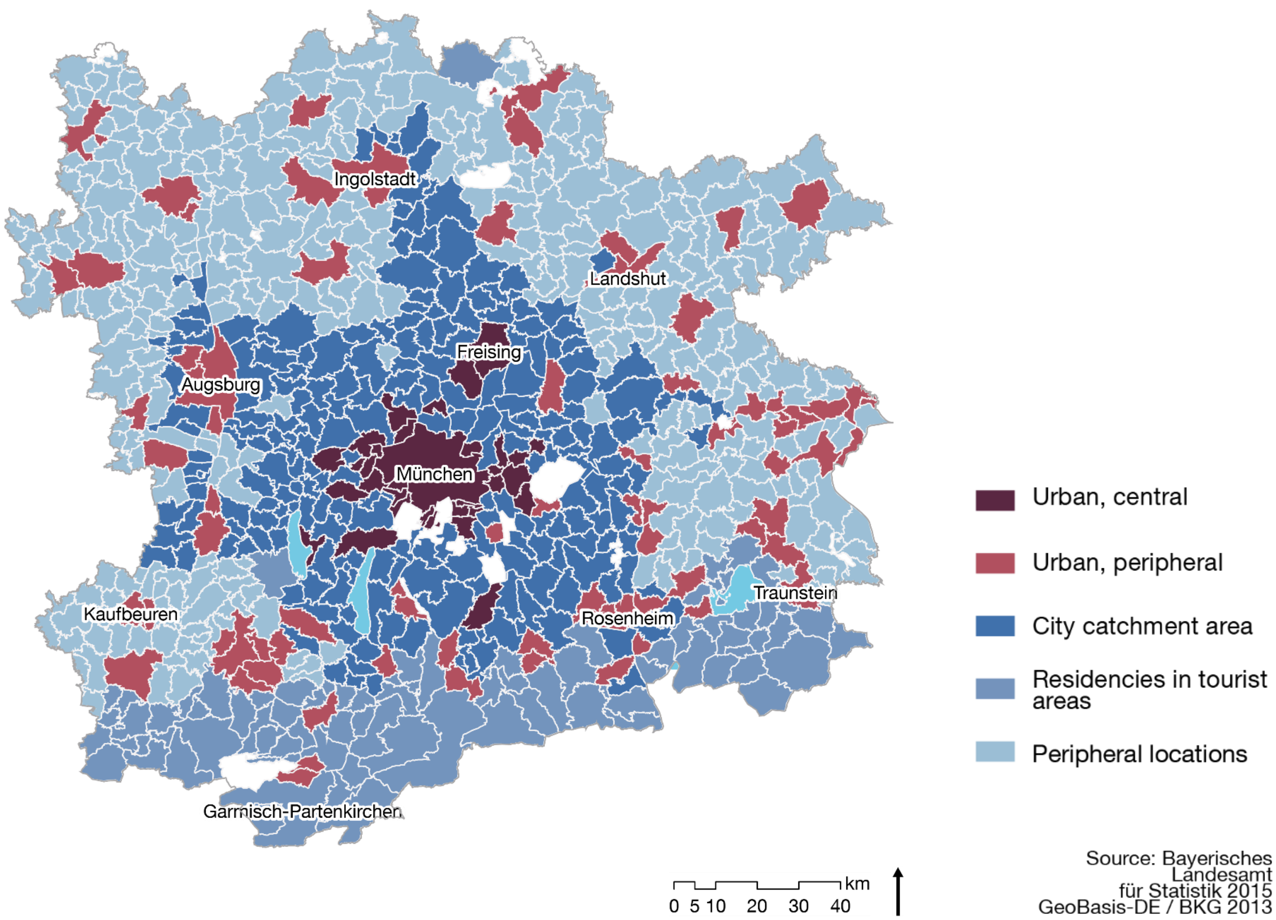


Figure 2A. Previous commute paths of other workers in the MMR.

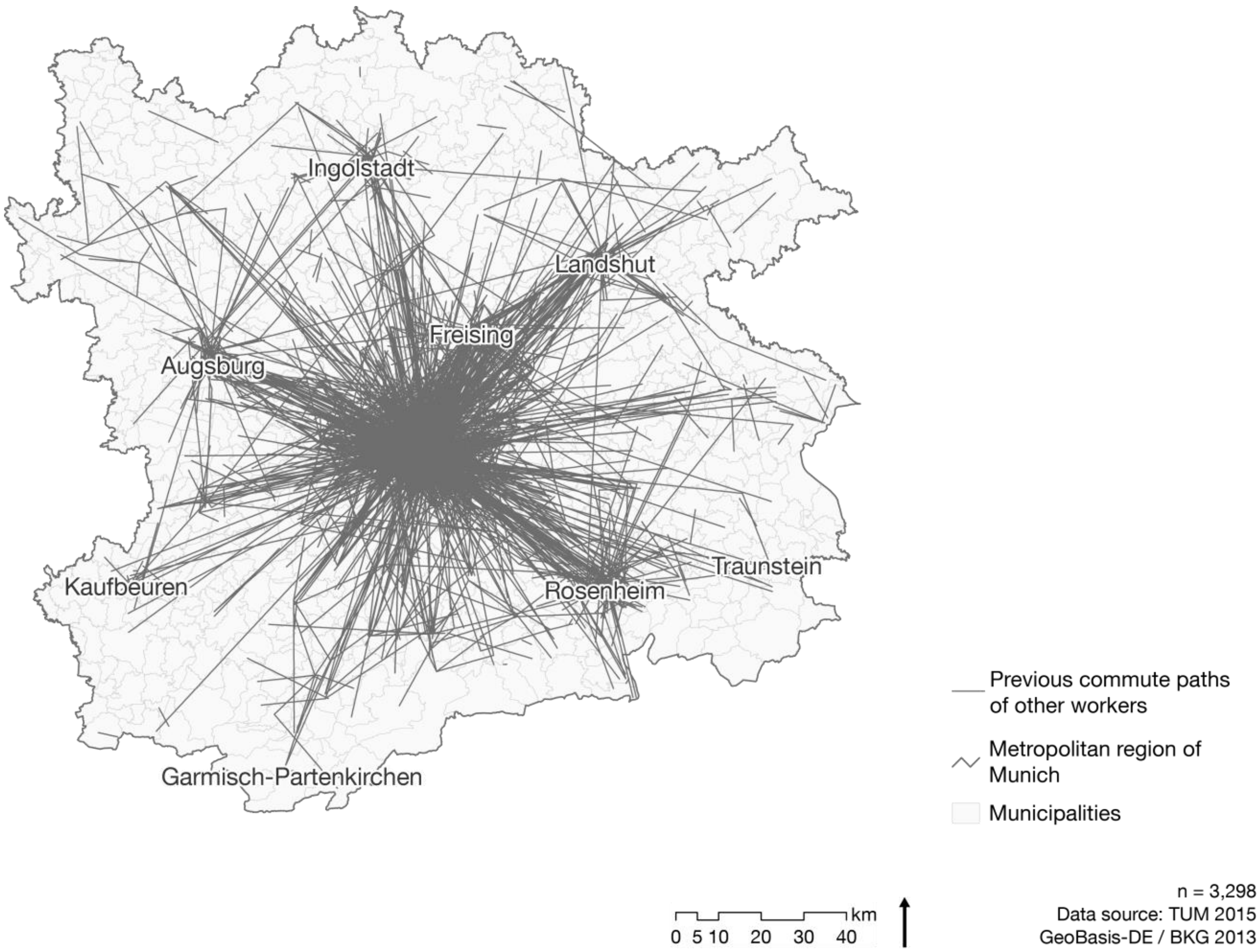


Figure 3A. Previous commute paths of symbolic APS-workers in the MMR.

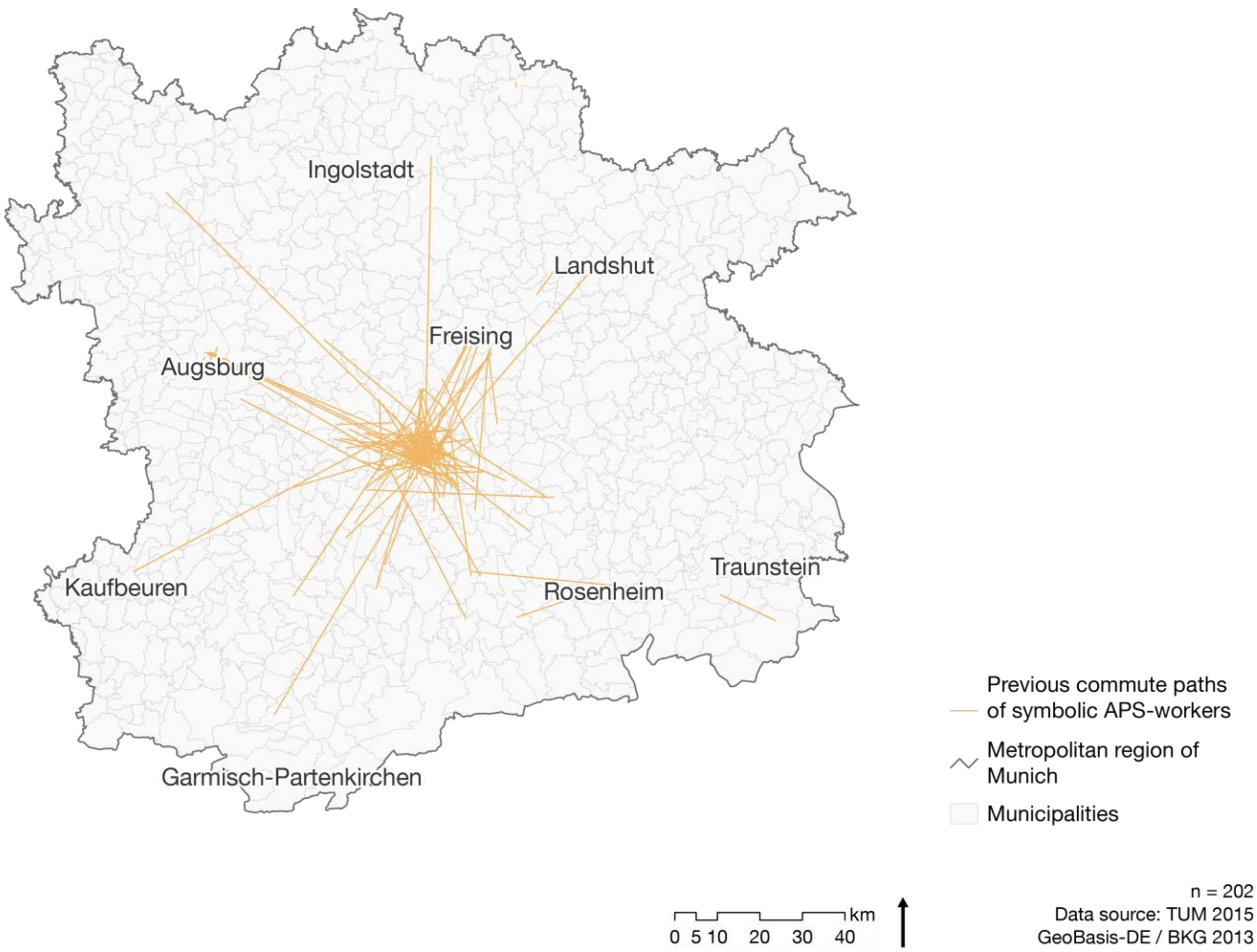


Figure 4A. Previous commute paths of synthetic APS-workers in the MMR.

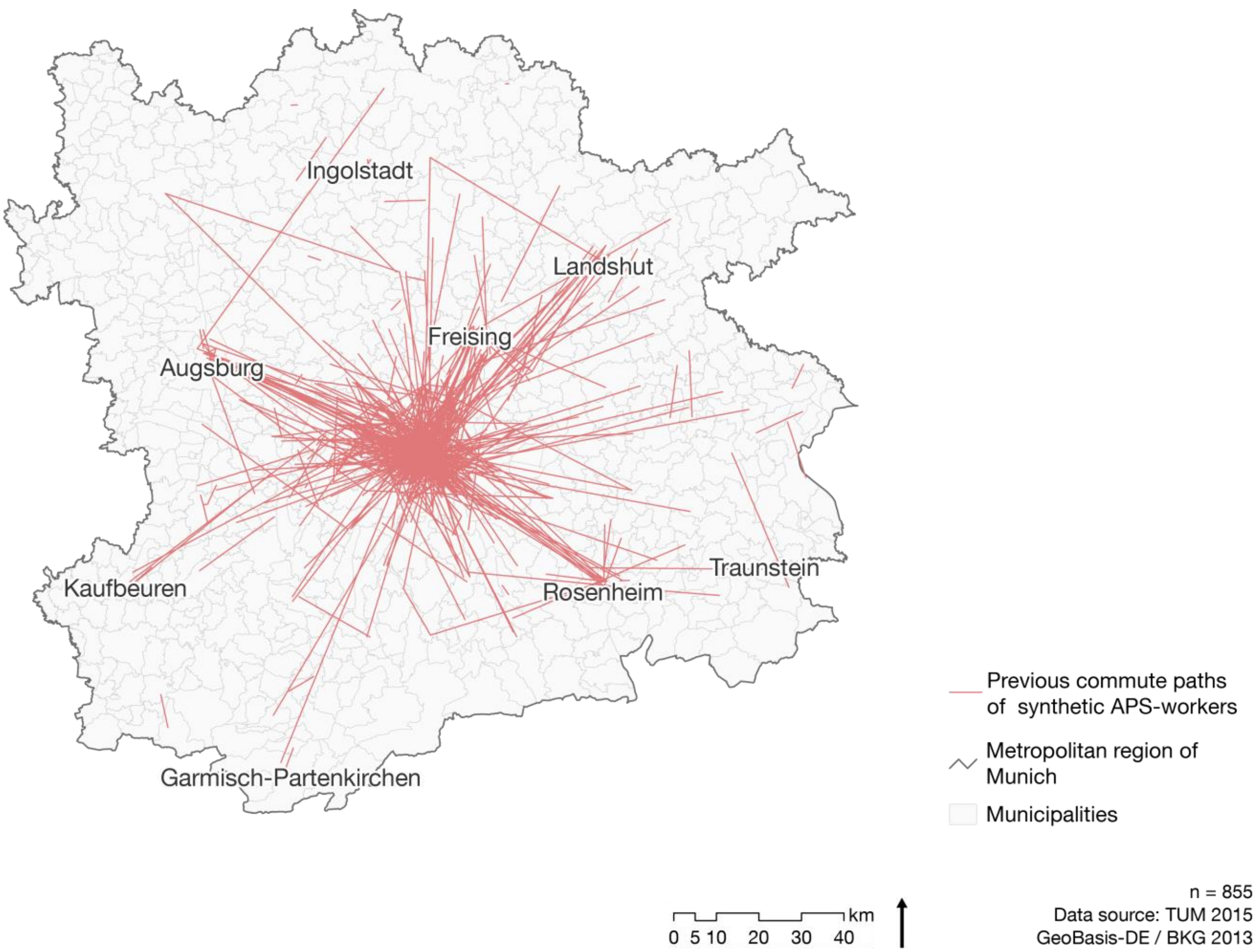


Figure 5A. Previous commute paths of analytical high-tech workers in the MMR.

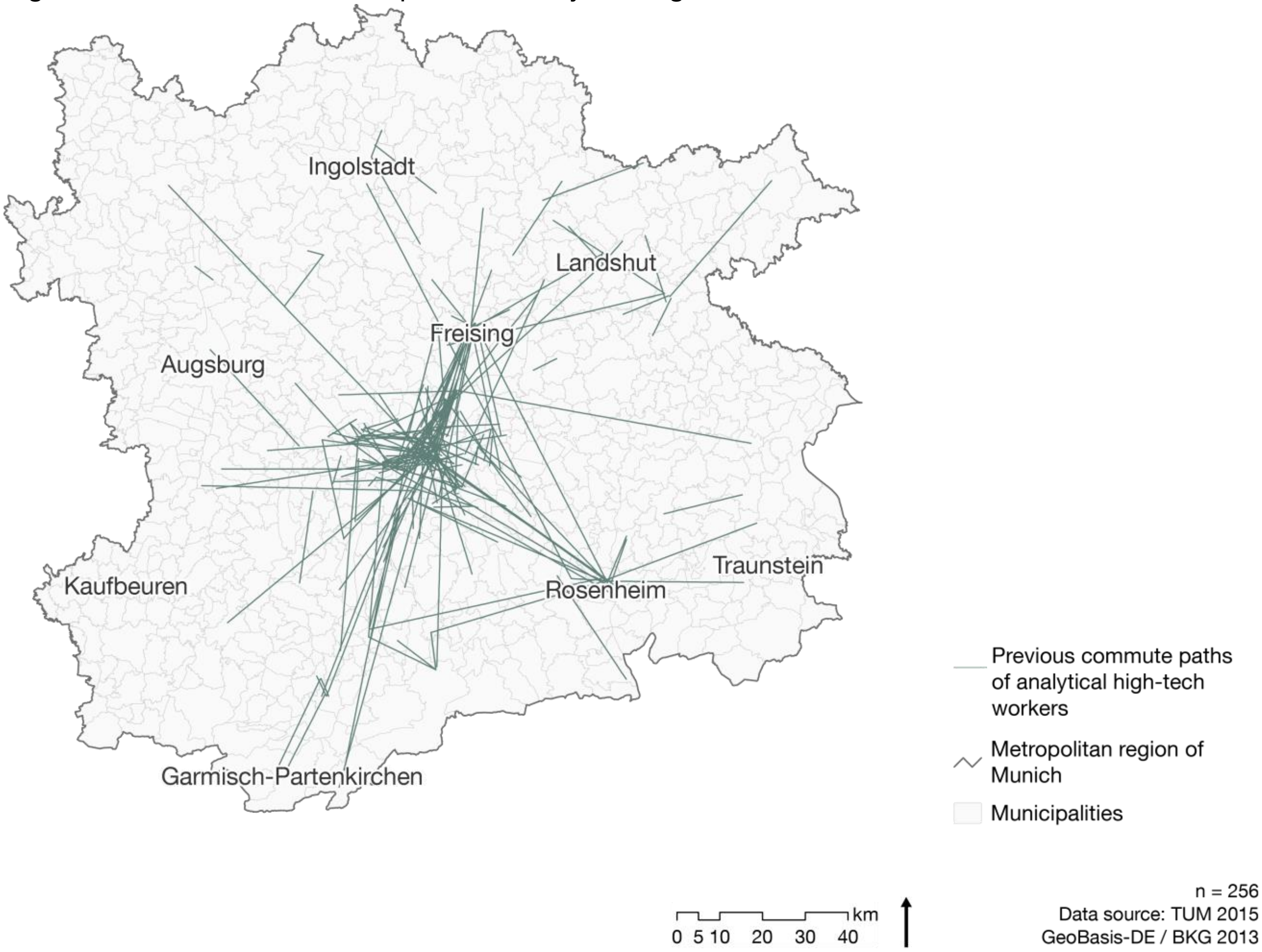


Figure 6A. Previous commute paths of synthetic high-tech workers in the MMR.

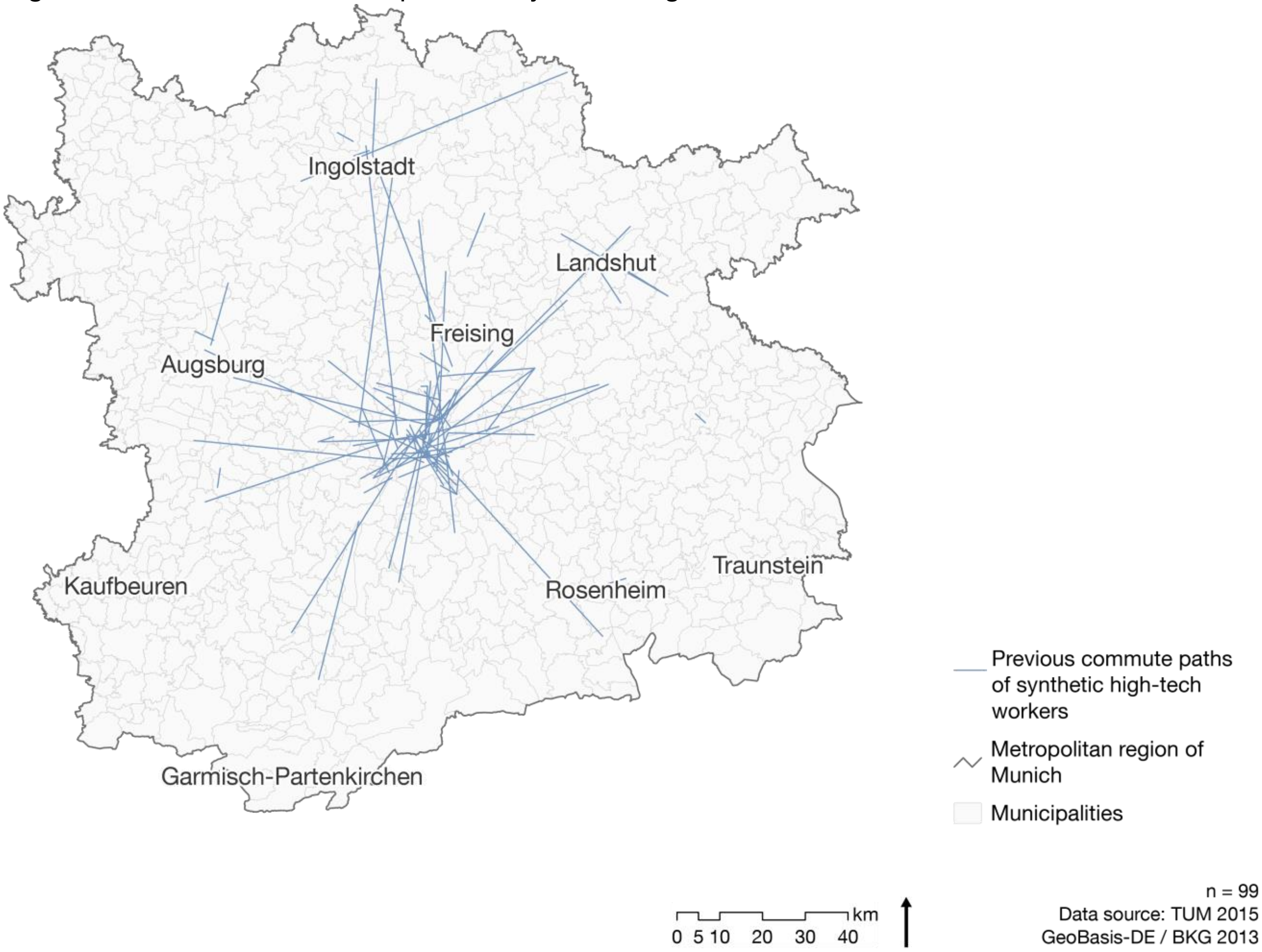


Figure 7A. Movement paths of other workers in the metropolitan region of Munich (left) and with a focus on the city of Munich (right).

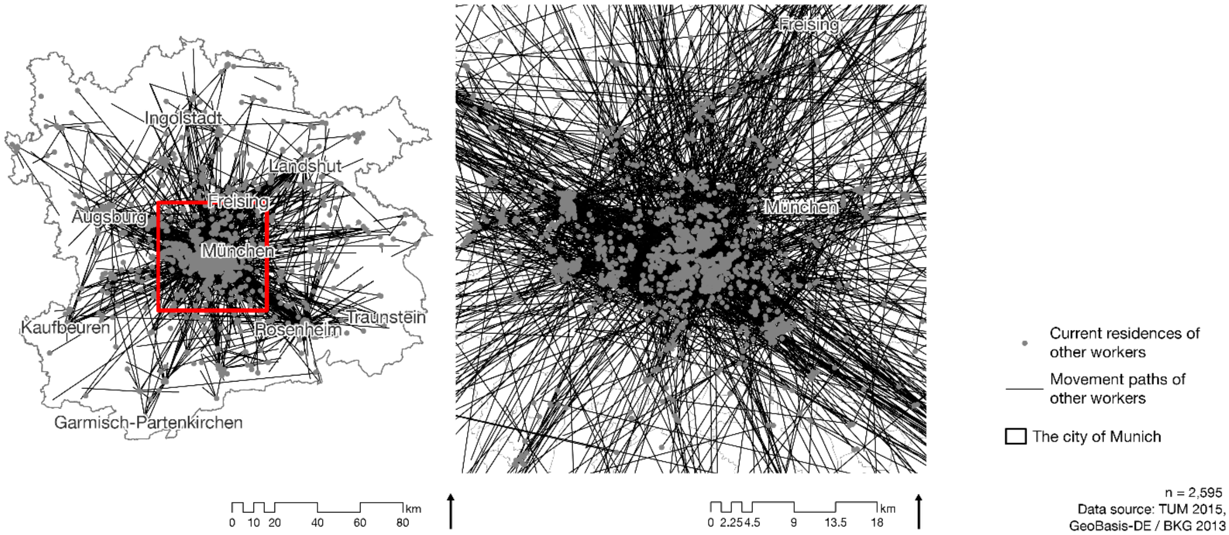


Figure 8A. Movement paths of symbolic APS workers in the metropolitan region of Munich (left) and with a focus on the city of Munich (right).

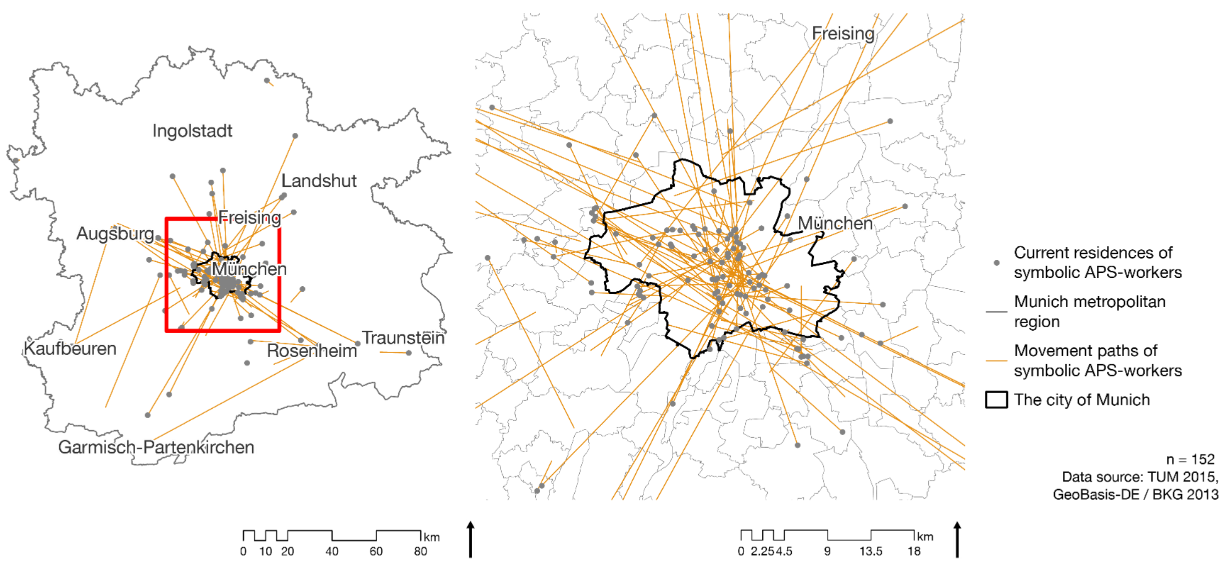


Figure 9A. Movement paths of synthetic APS workers in the metropolitan region of Munich (left) and with a focus on the city of Munich (right).

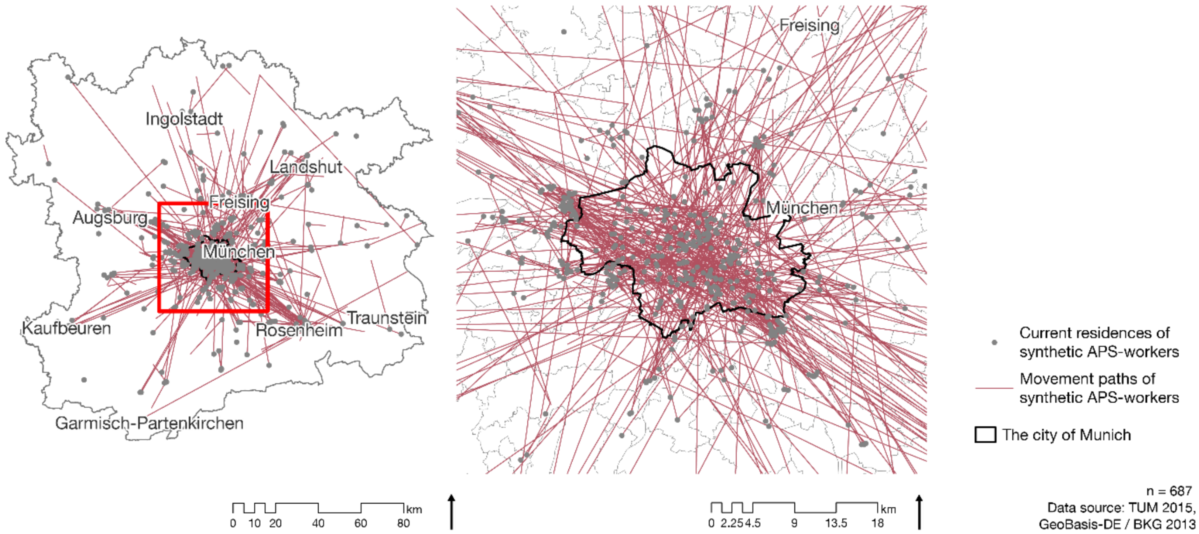


Figure 10A. Movement paths of analytical high-tech workers in the metropolitan region of Munich (left) and with a focus on the city of Munich (right).

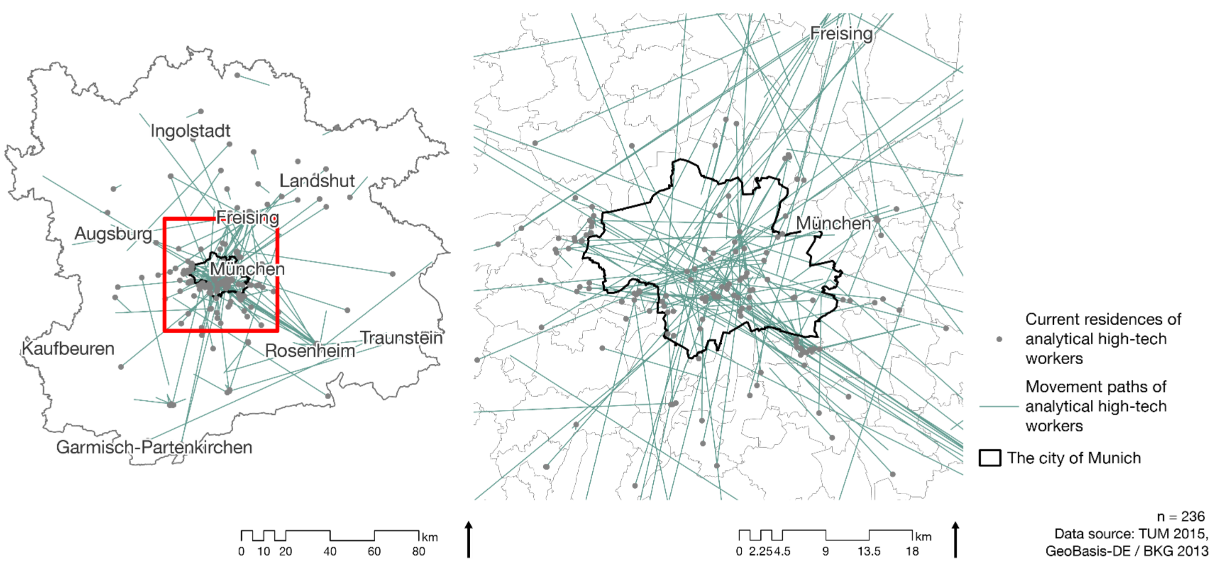
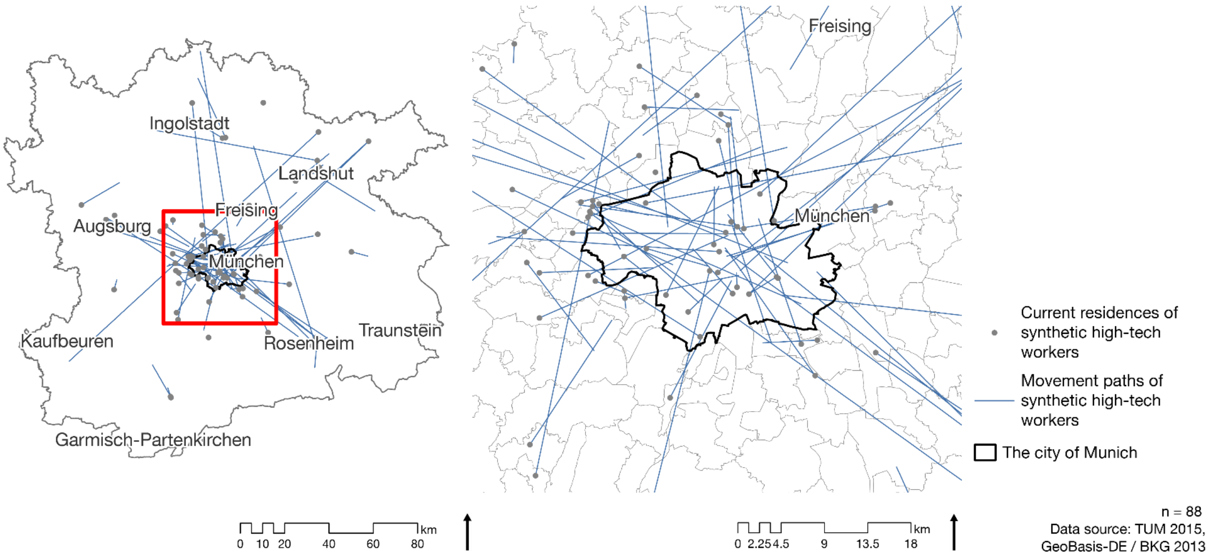


Figure 11A. Movement paths of synthetic high-tech workers in the metropolitan region of Munich (left) and with a focus on the city of Munich (right).



C Other relevant tables

Table 12A. Correspondence table between economic branches and occupation groups [Source: Thierstein, Goebel and Lüthi (2007: 29)].

Branches in High-Tech industry (in brackets: NACE 2003)	**High-Tech Occupations (in brackets: KldB 2010)**
Chemistry & Pharmacy: (2330, 2413, 2414, 2416, 2417, 2420, 2441, 2442, 2451, 2461,2463, 2464, 2466, 2511, 2513, 2615)	Mathematics, Biology, Chemistry and Physics Occupations (41) Medical Health Occupations (81)
Machinery & Vehicle construction (2911, 2912, 2913, 2914, 2924, 2931, 2932, 2941, 2942, 2943, 2952, 2953, 2954, 2955, 2956, 2960, 3410, 3430, 3511, 3520, 3530)	Machinery and vehicle technology occupations (25)
Electronics (3110, 3120, 3140, 3150, 3161, 3162, 3210, 3320, 3330)	Mechatronics, energy and electrical trades occupations (26)
Medical & optical instruments (3310, 3340)	Professions in medicine, orthopedic and rehabilitation equipment (825) Precision optics production occupations (2136) Technical research, development, design u. Production management occupations (27)
Branches in APS sector (in brackets: NACE 2003)	APS Occupations (in brackets: KldB 2010)
Banking & Finance; Insurance; Accounting 6511, 6512, 6521, 6522, 6523, 6711, 6712, 6713, 7011, 7012	Occupations in insurance and financial services, accounting and tax advice (72)
Advertising & Media (7440, 2211, 2212, 2213, 2214, 2215, 9211, 9220, 9240)	Occupations in advertising, marketing, commercial and editorial media (92)
Information and Communication Services (6430, 7221, 7230, 7240, 7250, 7260) Management- & IT-Consulting (7210, 7222, 7413, 7414, 7415)	IT, Information and communication Technology occupations (43)
Design, Architecture & Engineering (7420, 7430)	Product design and handicraft professions, visual arts, musical instruments (93) Planning, architectural and surveying professions (31)
Law (7411)	Occupations in Law and Administration (73) Occupations in Business Management and -Organization (71)

Table 13A. Distribution of each occupation groups among the respondents [Data source: Thierstein et al. (2016)]

Haupterwerbstätigkeit	Frequency	Share (%)
Produktdesign und kunsthandwerkliche Berufe, bildende Kunst, Musikinstrumentenbau	4	0.2
Feinoptik-Produktionsberufe	4	0.2
Maschinen- und Fahrzeugtechnikberufe	102	5.1
Mechatronik-, Energie- und Elektroberufe	33	1.6
Technische Forschungs-, Entwicklungs-, Konstruktions- u. Produktionssteuerungsberufe	63	3.1
Bauplanungs-, Architektur- und Vermessungsberufe	126	6.3
Medizinische Gesundheitsberufe	117	5.8
Berufe in der Medizin-, Orthopädie- und Rehatechnik	7	0.3
Lehrende und ausbildende Berufe	105	5.2
Geistes-, sozial- und wirtschaftswissenschaftliche Berufe	163	8.1
Berufe in Unternehmensführung und –organisation	222	11.0
Berufe in Versicherungs- und Finanzdienstleistungen, Rechnungswesen und Steuerberatung,	177	8.8
Berufe in Recht und Verwaltung	183	9.1
Berufe in Werbung, Marketing, kaufmännischen und redaktionellen Medien	133	6.6
Mathematik-, Biologie-, Chemie- und Physikberufe	178	8.8
Informatik-, Informations- und Kommunikationstechnologieberufe	397	19.7
Total	2014	100

Table 14A. Detailed information of indicators included in the cluster analysis (Authors' own illustration).

Indicators	Unit	Source	Year
Population density	Number of inhabitants per km^2	INKAR	2012
Employment density	Number of workers per km^2	Bayrisches Landesamt für Statistik	2013
Commute balance	Number of commuters	INKAR	2012
Residential rental cost	Euro per m^2	Immobilien Scout GmbH	2014
Density of schools	Number of schools per inhabitant	ATKIS/TIM	2014
Density of long-term shopping and services	Number of long-term shopping and services per inhabitant	Bisnode	2009
Density of cultural facilities	Number of cultural facilities per inhabitant	Bisnode	2009
Density of leisure facilities	Number of leisure facilities per inhabitant	Bisnode	2009
Density of daily shopping and services	Number of daily shopping and services per inhabitant	Bisnode	2009
Built-up ratio	Share of settlement and transport areas	INKAR	2011
Employment rate	Share of workers among the population at the age group of 15 to 60	INKAR	2012
Share of highly qualified employee	Share of workers with university or technical college degree among the total workers	INKAR	2011
Density of High-tech firms	Number of firms per km^2	Bisnode	2009
Density of APS firms	Number of firms per km^2	Bisnode	2009
Gravitational accessibility of potential population with private motorized transport	Number of inhabitants	TUM Accessibility atlas	2013
Gravitational accessibility of potential workplaces with private motorized transport	Number of workplaces	TUM Accessibility atlas	2013
Gravitational accessibility of potential workplaces with private motorized transport	Number of inhabitants	TUM Accessibility atlas	2013
Gravitational accessibility of potential workplaces with private motorized transport	Number of workplaces	TUM Accessibility atlas	2013

Table 15A. Rotated component matrix with coefficients between each indicator and the component. (Author's own calculation; Coefficients less than 0.40 are not displayed.)

	Components			
Indicators	Accessibility	Service	Knowledge intensity	Labor market
Population density	0.42	0.71		
Employment density			0.81	
Commute balance		0.40		
Residential rental cost	0.63			
Density of schools		0.80		
Density of long-term shopping and services		0.80	0.43	
Density of cultural facilities		0.83		
Density of leisure facilities		0.70		
Density of daily shopping and services		0.85		
Built-up ratio			0.81	
Employment rate				0.90
Share of highly qualified employees	0.73			
Density of high-tech knowledge-intensive firms			0.80	
Density of APS knowledge-intensive firms	0.42		0.79	
Gravitational accessibility of potential population with private car	0.94			
Gravitational accessibility of potential workplaces with private car	0.94			
Gravitational accessibility of potential workplaces with public transport	0.81			
Gravitational accessibility of potential workplaces with public transport	0.82			

Table 16A. Mean component score and indicator value of each spatial-functional cluster. (Author's own calculation; highest score are marked in bold)

	Mean value for each spatial-functional cluster				
Components	Knowledge intensive, well accessible metropolitan core	City catchment areas with good accessibility	Areas with relatively good services	Peripheral areas	Secondary cities with good services and high employment rate
Accessibility	**1.64**	**1.59**	-0.49	-0.36	-0.68
Service	0.52	0.08	0.86	-0.46	**2.33**
Knowledge intensity	**4.33**	-0.43	-0.45	-0.03	0.51
Labor market	-0.33	0.07	-1.13	0.19	**0.58**
Indicators					
Population density per km^2	3492.46	2014.47	1659.06	1174.40	2769.74
Employment density per km^2	1076.53	117.46	47.33	40.15	351.09
Commute balance	22.87	-87.54	-46.79	-126.98	1.46
Residential rental cost (Euros per sqm)	11.40	9.15	7.74	5.25	7.83
Density of schools	1.05	0.70	0.80	0.50	1.80
Density of long-term shopping and services	68.10	25.38	28.63	11.86	53.23
Density of cultural facilities	7.32	3.21	5.88	1.91	7.83
Density of leisure facilities	12.22	9.88	9.56	6.20	13.21
Density of daily shopping and services	18.97	8.74	10.40	4.21	16.92
Built-up ratio	54.96	16.06	8.46	11.16	26.86
Employment rate	56.44	57.08	52.24	57.47	57.80
Share of highly qualified employee	23.21	14.53	8.51	7.88	8.83
Density of High-tech firms	8.42	1.29	0.42	0.32	1.90
Density of APS firms	84.70	7.27	2.99	1.59	11.68
Gravitational accessibility of potential population with private motorized transport	1460480.76	1176145.79	479637.75	549351.92	629380.50
Gravitational accessibility of potential workplaces with private motorized transport	655141.76	506519.17	191612.61	218893.92	254046.41
Gravitational accessibility of potential workplaces with private motorized transport	1059399.22	588996.77	161052.25	171606.69	324622.31
Gravitational accessibility of potential workplaces with private motorized transport	521165.65	279902.74	68715.69	76343.79	143070.29

Table 17A. Socio-demographics and spatial choices of knowledge workers in the survey (Author's own calculation).

Variable	Categories (%)			
Subgroups	Analytical high-tech workers	Symbolic APS-workers	Synthetic APS-workers	Synthetic high-tech workers
	18.4	13.6	60.1	7.9
Gender	Female	Male		
	33.0	67.0		
Age	Age 18-30	Age 30-39	Age 40-49	Age 50-59
	19.0	44.6	24.5	10.3
Household size	Single-person	Single-parent	Two-person	Family
	17.0	2.1	40.1	31.2
Level of education	No university degree	With university degree		
	25.0	75.0		
Income level	Low income level	Medium income level	High income level	
	6.9	39.4	53.7	
Car availability	Private car	Company car	According to need	No availability
	64.0	10.2	14.6	11.2
Residence centrality	Central residence	Peripheral residence		
	63.0	37.0		
Job centrality	Central job location	Peripheral job location		
	43.0	57.0		
Commute mode	Car	Public transport	Cycling	Walking
	44.6	36.3	15.3	3.8

Table 18A. Descriptions and distribution of dependent and independent variables (Author's own calculation).

Dependent variable	*Categories*	*Descriptions*	*Shares*
Joint residential location and commute mode choice	0	Peripheral residence and commute with car	29.3%
	1	Central residence and commute with car	9.9%
	2	Central residence and commute with public transport	24.3%
	3	Central residence and commute with cycling/walking	9.9%
	4	Peripheral residence and commute with public transport	20.5%
	5	Peripheral residence and commute with cycling/walking	6.1%
Residential location centrality	1	Residence is located within central areas	41.8%
	0	Residence is located outside of central areas	58.2%
Commute transport mode	2	Commute with public transport	41.0%
	1	Commute with cycling or walking	17.3%
	0	Commute with car	41.7%

Independent variables	Categories	Descriptions	
Workplace centrality	1	Workplace is located within central areas	67.1%
	0	Workplace is located outside of central areas	32.9%
Gender	1	Female	48.9%
	0	Male	51.1%
Household net income level	High	Larger than 4000 Euros per month	47.5%
	Medium	2000-4000 Euros per month	38.6%
	Low	Less than 2000 Euros per month	13.9%
Houeshold type	Single person	Sinlge person in the household	23.0%
	Single parent	One employed person with children	2.1%
	Two person	Two earner household	38.2%
	Family	Couples with children in the household	10.5%
Auto affinity	1	Mention only importance of car travel at residence	64.0%
	0	The rest of the workers	36.0%
Car access	Private car	Privately owned car	65.2%
	Company car	Car offered by the company	4.4%
	According to arrangement or Use car sharing services	Car is available when it is arranged, or use car sharing services	14.9%
	No car	No access to car	15.5%
Commute time using public transport versus car	≤2.7	Time using public transport versus car is less than or equal to 2.7	58.6%
	>2.7	Time using public transport versus car is larger than 2.7	41.4%
Knowledge worker group	Other workers	workers that do not belong to knowledge workers	71.0%
	Analytical high-tech workers	workers using analytical knowledge in high-tech industries	5.3%
	Symbolic APS-workers	workers using symbolic knowledge in APS sectors	1.9%
	Synthetic APS-workers	workers using synthetic knowledge in APS sectors	19.6%
	Synthetic high-tech workers	workers using synthetic knowledge in high-tech industries	2.2%

Table 19A. Robustness test of logistic regression model for residential location choice (Authors' own calculation).

Variables	Model 3 in Table 6				Model 4 in Table 6			
	B	sig.	confidence lower	interval upper	B	sig.	confidence lower	interval upper
Constant	-2.82	0.00	-3.74	-2.12	-2.59	0.00	-3.35	-2.01
Household: Family (ref)								
Single person	0.65	0.00	0.46	0.84	0.67	0.00	0.42	0.90
Single parent	0.21	0.33	-0.24	0.65	0.58	0.01	0.04	1.08
Two-person	0.28	0.00	0.12	0.47	0.44	0.00	0.27	0.62
Household income: Medium income (ref)								
Lowest income	-0.07	0.50	-0.27	0.15	1.19	0.09	-19.98	22.29
Highest income	0.08	0.30	-0.09	0.23	0.69	0.11	-0.19	1.62
Gender: Male (ref)								
Female	-0.04	0.56	-0.17	0.11	-0.05	0.44	-0.20	0.08
Education level: With university degree (ref)								
Without university degree	-0.49	0.00	-0.62	-0.36	-0.44	0.00	-0.58	-0.30
Auto affinity: with (ref)								
without auto affinity	0.92	0.00	0.57	1.33	0.86	0.00	0.42	1.39
Jo centrality: peripheral jo (ref)								
Central jo location	2.06	0.00	1.21	3.17	1.04	0.00	0.90	1.20
Car ownership: Private car (ref)								
Company car	-0.07	0.60	-0.33	0.19	0.34	0.03	0.01	0.62
According to need	0.26	0.01	0.06	0.47	0.37	0.00	0.15	0.61
Car sharing	1.25	0.00	0.91	1.59	1.39	0.00	1.00	1.79
No car	0.95	0.00	0.77	1.14	1.10	0.00	0.90	1.31
Subgroups: synthetic high-tech workers (Ref)								
Other workers	-0.07	0.60	-0.33	0.19	0.38	0.28	-0.29	1.17
Analytical high-tech workers	0.26	0.01	0.06	0.47	0.15	0.74	-0.76	1.16
Symbolic APS-workers	**1.25**	0.00	0.91	1.59	**0.78**	0.06	-0.04	1.79
Synthetic APS-workers	0.95	0.00	0.77	1.14	**0.63**	0.07	-0.06	1.42
Subgroups: high-tech workers (ref) interact with workplace centrality: non-central workplace (ref)								
Other workers by Central workplace	**-0.86**	0.06	-1.91	-0.03				
Analytical KW by Central workplace	**-1.24**	0.01	-2.32	-0.30				
Symbolic KW by Central workplace	-1.06	0.05	-2.34	0.06				
APS KW by Central workplace	-0.89	0.06	-1.84	-0.04				
Subgroups: high-tech workers (ref) interact with income level: medium income level(ref)								
Other workers by low income level					-1.23	0.09	-22.04	19.52
Analytical KW by low income level					-0.32	0.64	-21.51	20.81
Symbolic KW by low income level					**-2.16**	0.02	-23.16	18.38
APS KW by low income level					**-1.78**	0.02	-22.80	19.15
Other workers by high income level					-0.71	0.10	-1.60	0.12
Analytical KW by high income level					-0.49	0.40	-1.63	0.52

Symbolic KW by high income level	-0.59	0.32	-1.68	0.53
APS KW by high income level	-0.84	0.07	-1.82	0.12

Table 20A. Robustness test of logistic regression models for commuting mode choice (Authors' own calculation).

Variables	Model 2 in Table 10							
	Transit compared to car				Active compared to car			
			Confidence interval				Confidence interval	
	B	Sig.	lower	upper	B	Sig.	lower	upper
Constant	-2.38	0.00	-4.19	-0.83	11.56	0.01	8.51	14.71
Household type: Familie (ref)								
Single-person	-0.04	0.84	-0.43	0.32	-0.80	0.00	-1.33	-0.32
Single-parent	-0.58	0.17	-1.37	0.19	-0.64	0.17	-1.59	0.28
Two-person	-0.24	0.10	-0.53	0.02	-0.62	0.01	-1.04	-0.23
Multi-person apartment	-0.02	0.93	-0.43	0.39	-0.44	0.12	-0.98	0.11
Education level: University degree (Ref)								
Without university degree	-0.28	0.02	-0.52	-0.06	-0.74	0.00	-1.07	-0.41
Gender: male (ref)								
Female	0.16	0.19	-0.09	0.41	-0.01	0.97	-0.32	0.31
Income level: medium level (ref)								
Lowest income level	-0.05	0.82	-0.47	0.40	-0.29	0.25	-0.78	0.14
Hightest income level	0.18	0.15	-0.07	0.44	0.02	0.92	-0.35	0.36
Commuting distance along road network								
Travel time PuT/Car=3 (Ref)								
Travel time PuT/Car=1	-0.15	0.77	-1.31	0.78	1.43	0.03	-18.51	2.87
Travel time PuT/Car=2	0.90	0.00	0.61	1.24	0.51	0.02	0.07	0.93
Travel time PuT/Car=4	-0.73	0.00	-1.02	-0.48	-0.27	0.18	-0.70	0.11
Travel time PuT/Car=5	-1.59	0.00	-2.02	-1.25	-0.78	0.00	-1.24	-0.38
Stated importance of car travel at residence (Ref)								
No Stated importance	0.55	0.00	0.27	0.84	1.32	0.00	0.95	1.70
Stated importance of car travel at workplace (Ref)								
No Stated importance	2.82	0.00	2.37	3.48	3.02	0.00	2.43	3.77
Private car (Ref)								
Company car	-1.63	0.00	-2.27	-1.19	-2.68	0.00	-4.16	-1.94
According to need or car sharing	1.83	0.00	1.46	2.32	1.56	0.00	1.09	2.09
No car	2.58	0.00	2.03	3.30	2.18	0.00	1.54	2.96
Workplace location: Non-Central workplace (Ref)								
Central workplace	1.10	0.00	0.83	1.39	0.61	0.00	0.27	1.00
Residence location: Non-Central residence (Ref)								
Central residence	0.72	0.00	0.47	0.98	0.69	0.00	0.34	1.04
Subgroups: synthetic high-tech workers (Ref)								
Other workers	**1.08**	0.03	0.14	2.27	1.53	0.07	-0.08	4.32
Analytical high-tech workers	0.32	0.59	-0.76	1.56	**2.09**	0.02	0.43	5.06
Symbolic APS-workers	0.83	0.19	-0.38	2.15	1.50	0.14	-0.32	4.43
Synthetic APS-workers	**1.14**	0.03	0.16	2.33	**1.83**	0.03	0.17	4.84

Table 21A. Robustness test of multinomial logistic regression models for the joint residential location and commute mode choice (Author's own calculation;* indicates 0.05 significant level)

Variables	Central residence, commtue with car			Central residence, commtue with public transport			Central residence, commtue with cycling/walking			Peripheral residence, commtue with public transport			Peripheral residence, commtue with cycling/walking		
		95% confidence level			95% confidence level			95% confidence level			95% confidence level			95% confidence level	
		lower	upper		lower	upper		lower	upper		lower	upper		lower	upper
Constant	-1.91	-1.93	-1.88	-4	-4.03	-3.98	-4.83	-4.88	-4.8	-4.23	-4.26	-4.2	-3.15	-3.19	-3.11
Gender: Male (ref)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Female	-0.16	-0.17	-0.15	0.07	0.06	0.07	0.11*	0.1	0.12	0	0	0.01	-0.04	-0.05	-0.03
Household type: Family (ref)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Single-person	0.64	0.63	0.65	1.24*	1.23	1.26	1.01	1	1.02	0.54*	0.53	0.55	0.37	0.36	0.39
Single-parent	0.63	0.61	0.65	-0.25	-0.27	-0.22	0.06	0.03	0.09	-0.44	-0.47	-0.41	0.19	0.16	0.22
Two-person	0.04	0.03	0.04	0.49*	0.48	0.5	0.26	0.25	0.27	0.07	0.07	0.08	-0.18	-0.19	-0.17
Multi-person apartment	0.39	0.37	0.4	0.74	0.72	0.75	0.61	0.6	0.63	0.52	0.51	0.53	0.05	0.03	0.07
Income level: medium level (ref)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lowest income level	-0.31	-0.32	-0.29	-0.14	-0.15	-0.13	-0.2*	-0.22	-0.19	-0.01	-0.02	0	-0.28	-0.29	-0.26
Highest income level	0.22*	0.21	0.23	0.3*	0.29	0.31	0.25*	0.24	0.26	0.3	0.29	0.31	0.08	0.06	0.09
Workplace location: Peripheral workplace (Ref)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Central workplace	0.37	0.37	0.38	1.87*	1.86	1.88	1.98*	1.97	1.99	1.79	1.78	1.8	0.21	0.2	0.22
Ratio of commute time using public transport and car: Ratio larger than or equal to 2.7 (Ref)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ratio of commute time smaller than 2.7	0.43*	0.43	0.44	1.4*	1.39	1.41	0.07	0.06	0.08	1.23*	1.23	1.24	-0.25*	-0.25	-0.24
Auto affinity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Without auto affinity	0.13	0.12	0.14	1.25	1.24	1.26	1.93	1.92	1.94	0.93	0.92	0.94	1.67	1.66	1.68
Private car (Ref)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Company car	0.14*	0.13	0.15	-1.92*	-1.94	-1.9	-2.68*	-2.73	-2.63	-1.94*	-1.96	-1.92	-1.69*	-1.72	-1.66
According to need or car sharing	-0.27	-0.29	-0.25	2.25*	2.23	2.26	2.24*	2.23	2.25	2.11*	2.09	2.12	1.9*	1.89	1.92
No car	1.04*	1.01	1.07	3.73*	3.71	3.75	3.6*	3.58	3.62	3.43*	3.41	3.45	2.84*	2.82	2.86

Subgroups: synthetic high-tech workers (Ref)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other workers	0.2	0.18	0.22	0.21*	0.18	0.23	0.62	0.59	0.67	1.03*	1.01	1.06	0.53	0.49	0.57
Analytical high-tech workers	0.22	0.2	0.25	-0.41	-0.43	-0.38	0.58	0.55	0.63	0.2	0.17	0.24	0.65*	0.61	0.69
Symbolic APS-workers	1.15	1.12	1.18	0.58*	0.55	0.62	1.15*	1.11	1.2	0.85	0.81	0.89	0.54	0.49	0.6
Synthetic APS-workers	0.46	0.44	0.48	0.48*	0.46	0.51	0.95*	0.92	1	1.12*	1.09	1.15	1.22	1.19	1.26

Remark: The scenario of peripheral residence and commute with cars is set as the reference category in the multinomial logistic regression.

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