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Residence, workplace and commute: Interrelated spatial choices of knowledge workers in the metropolitan region of Munich

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ABSTRACT

Knowledge workers (KW), as important individual agents who embody, exchange, create and exploit knowledge, contribute to regional competitiveness and growth. To attract and retain them in a region, it is necessary to have a better understanding of their fundamental spatially-related behaviors including residence, workplace, and commute choices. In this study, we depart from a perspective of knowledge typology (analytical-synthetic-symbolic knowledge base) to investigate the heterogeneity of knowledge workers' residence, workplace, and commute choices. The case study was conducted in the metropolitan region of Munich. Various types of data are integrated: structural statistical and individually-based web-survey data; individuals' actual choices and their assessment of importance for each criterion; positional and relational data. We find that symbolic Advanced-Producer-Services (APS) workers tend to reside in central areas and use public transport or active modes to commute. In contrast, synthetic high-tech workers are found in relatively peripheral areas and depend more on cars to reach their workplaces. The spatially-related choices of analytical high-tech and synthetic-APS workers are positioned in between symbolic APS-workers and synthetic high-tech workers. We reach 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 between interrelated spaces surrounding residence, workplace, as well as along 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 commute mode. These conclusions may provide insights for urban planners and policy-makers regarding the attraction and retention of knowledge workers.

1. Introduction

Knowledge has become a crucial factor for production in the era of knowledge economies (Simmie, 2002). The capacity and speed of new knowledge creation constitute competitive advantages for knowledge-intensive firms, stimulating regional long-run growth (Bathelt and Glückler, 2011; Storper and Scott, 2009). Exchanging and creating knowledge often require face-to-face interaction between knowledge agents in “a specific time and space” (Nonaka and Nishiguchi, 2000, p. 19), since knowledge has a tacit component, which cannot be codified easily (Boschma, 2005; Polanyi, 1966; Spencer, 2015; Storper and Venables, 2004). Knowledge workers, as individual agents who embody, exchange, create, and exploit knowledge, are indispensable resources for innovation and forces for regional development (Vissers and Dankbaar, 2013). We define knowledge workers based on their employment sector and the complexity of their professional tasks. Firstly, knowledge workers work in high-tech industries or advanced-producer-services (APS), which are two main pillars of the knowledge economy (Lüthi et al., 2010; Thierstein et al., 2008). Secondly, knowledge workers perform non-routine or highly complex tasks, and fulfill important functions in their organizations (Brinkley et al., 2009; Bundesagentur für Arbeit, 2010, p. 27).

The economic vitality of the metropolitan region of Munich is largely attributable to knowledge workers functioning as ‘innovation engines’ (Hafner et al., 2007, p. 40). However, Willems and Hoogerbrugge (2012) predict that this region will still have a large demand for knowledge workers in the future. Housing, employment, and mobility are three fundamental considerations determining whether one settles in a region for a longer period or not. To attract and retain more knowledge workers within the metropolitan region of Munich, it is necessary to have a better understanding of their choices of residence, workplace, and commute mode. Existing research on spatially-related behaviors of knowledge workers has been conducted either in different spatial scales, or within a specific spatial context like the Netherlands, Sweden, the United States, or Canada (Asheim and Hansen, 2009; Burd, 2012; Musterd, 2004; Spencer, 2015). In addition, existing studies on

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the driving force for the spatial process by knowledge workers are inconclusive so far (Frenkel et al., 2013b). On the one hand, knowledge workers revitalize and regenerate urban core areas, contributing to the concentration process (Brake, 2015). On the other hand, knowledge workers encourage urban sprawl via their residential location (Felsenstein, 2002).

We investigate the heterogeneous spatially-related choices made by different types of knowledge workers and aim to identify the traces of the knowledge base. Specifically, we wish to establish which kind of locations are ideal for which types of knowledge workers to reside in, and which commute mode they prefer to use. Furthermore, we discuss the underlying rationales for the choices they make. Our study may provide insights for policy-makers and urban planners by identifying the spatially-related revealed preferences of each type of knowledge workers.

The remainder of this paper is organized as follows: Section 2 elaborates our conceptual background and research hypothesis. We follow this by introducing our methodology, including the research design and methods of analysis, in Section 3. Section 4 presents the results of our analysis and a discussion of the implications. Finally, we reach our conclusions and remark on the research outlook.

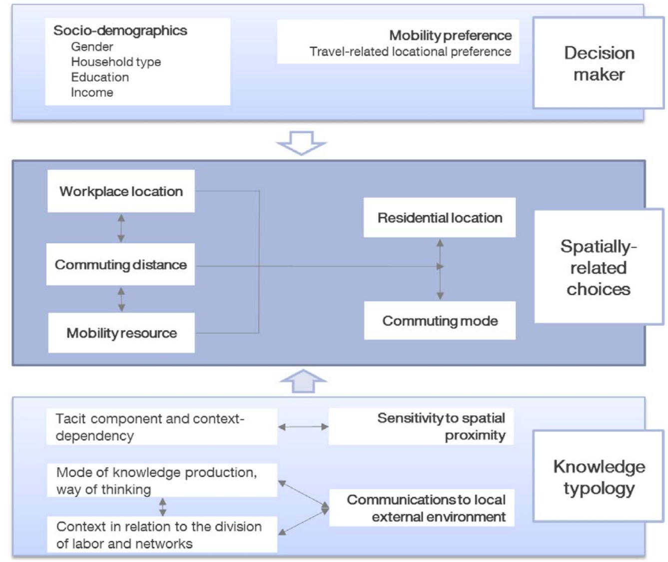

Fig. 1. A comprehensive framework of spatially-related choices and its relation to the characteristics of the decision maker and the knowledge typology.

2. Knowledge typology, sensitivity to distance, and spatially-related revealed preference

The comprehensive framework of analysis for studying spatially-related choices is shown in Fig. 1. Both the characteristics of individual decision-makers and knowledge typology influence the spatially-related choices of knowledge workers. Section 2.1 mainly focuses on the connection between spatially-related choices and the characteristics of individual decision-makers. Afterwards, the linkage between spatial choices and the knowledge typology will be elaborated in the subsequent Sections 2.2–2.4. Firstly, we introduce the analytical-synthetic-symbolic knowledge typology and discuss their different sensitivities to distance. Secondly, we introduce different modes of knowledge creation and the concept of ‘context’, and discuss their implications for various locational patterns of knowledge-intensive firms in different economic sectors. Thirdly, we emphasize the relevance of residence, workplace, and commute in the social learning of knowledge workers. Based on these theoretical and empirical findings, we come up with the hypothesis at the end of the section.

2.1. Spatially-related choices and characteristics of individual decision-makers

As shown in Fig. 1, spatially-related choices include the interrelated choice of residential location and commute mode (Cao, 2015), as well as the conditioning aspects including job location, commute distance/time and the car ownership (Lawton et al., 2013; Van Acker and Witlox, 2010). Characteristics of individual decision-makers include socio-demographics and mobility preferences of individuals. With respect to residential choice, each individual wants a favorable dwelling with good accessibility to current and potential destinations or opportunities (Thierstein et al., 2013). Individuals with certain socio-demographics and attitudes towards certain travel modes make different trade-offs. Firstly, family households usually seek residences with direct access to the natural environment to maintain children's optimal health and development (Cummins and Jackson, 2001). Younger knowledge workers tend to select the city center, whereas older knowledge workers tend to select the quiet neighborhoods in suburban areas (Andersen et al., 2010; Beckers and Boschman, 2013; Lawton et al., 2013). Regarding the relative importance of jobs and amenities in determining residential location choice, Niedomysl and Hansen (2010) found that work opportunities are considered more important in making a migration decision among highly educated migrants compared to those with lower education. Secondly, mobility preference will simultaneously influence the choice of residential location as well as the commute mode. An individual who prefers cycling would live in neighborhoods with good cycling-facilities (Pinjari et al., 2009, p. 730). The residential and job locations simultaneously affect both the commute distance and the relative advantage of a certain commute mode among many alternatives in terms of travel time, which in turn influence the commute mode choice (Limtanakool et al., 2006). In addition, mobility resources, such as the ownership of a car and the time and monetary budget for the commute, also influence the choice of a certain mode (Paleti et al., 2013).

2.2. Knowledge typology and sensitivities to spatial proximity

Knowledge is a complex term. Knowledge that can be expressed with codified language is termed codified knowledge. Knowledge that cannot be (easily) codified is embodied in individuals. This would include subjective insights, as well as understanding and intuitions, and is termed tacit knowledge (Nonaka and Nishiguchi, 2000; Polanyi, 1966). However, the binary categorization of knowledge as either codified or tacit has been criticized as demonstrating an inadequate understanding of knowledge, learning and innovation (Asheim et al., 2011, p. 896; Johnson et al., 2002). To go beyond this simple dichotomy, Asheim et al. (2007) introduced the analytical-synthetic-symbolic knowledge typology, which “takes account of the rationale of knowledge creation, the way knowledge is developed and used… and the interplay between actors in the processes of creating, transmitting and absorbing knowledge” (Asheim et al., 2011, p. 897). Analytical knowledge, also known as ‘know-why’, concerns principles and causalities. It aims to understand and explain features of the material or natural world (Spencer, 2015, p. 886). Synthetic knowledge, often referred to as ‘know-how’, involves skills and procedures (Moodysson et al., 2008, p. 1045). Synthetic knowledge helps to solve practical problems by combining existing knowledge. Symbolic knowledge is related to “the aesthetic attributes of products, to the creation of designs and images and to the economic use of various cultural artefacts" (Asheim et al., 2007, p. 145). 'Know-who', knowledge about other potential collaborators, is crucial in symbolic knowledge (Asheim et al., 2011, p. 897).

These three knowledge bases have "different sensitivity to geographical distance" (Asheim et al., 2011, p. 897). The larger the tacit component and the more dependent on the specific context the knowledge is, the more sensitive to distance decay and more locally oriented knowledge exchange and creation tend to be (Moodysson et al., 2008, p. 1052). Analytical knowledge can be codified efficiently, the meaning is relatively constant between places, which makes it less sensitive to geographical separation, and occasional exchanges can be realized in a long-distance network (Storper & Venables, 2004, p. 356). In contrast, symbolic knowledge creation relies heavily on frequent interactions with local people through co-present meetings, because it has a strong tacit component and its meaning varies across different places, classes and genders. For instance, cultural and media industries in New York City that draw mainly on symbolic knowledge are in dense urban areas, as urban areas allow "these processes of cross-fertilization, networking, and low transaction costs to accessing gatekeepers, jobs, and labor pools to occur" (Currid & Connolly, 2008, p. 431). Synthetic knowledge lies on a continuum between symbolic and analytical knowledge. It is to some extent context specific, but the exchange can also be facilitated by information and communication technology. For instance, within software industries, which primarily use synthetic knowledge defined by Pina and Tether (2016), informal knowledge flows via knowledge spillovers and informal networks are highly significant at all spatial scales (Trippl et al., 2009).

2.3. Mode of knowledge production, 'context', and communications to the external environment

Different modes of knowledge production associated with each knowledge base correspond to distinct ways of thinking and different requirements for frequent face-to-face interactions. Consequently, this will tend to have an impact on the spatial patterns. The exploitation and creation of symbolic knowledge depends on both the creator and evaluator (Amabile, 1996), and is termed heuristic knowledge production. 'Divergent thinking', allowing various solutions to one open problem, is highly relevant in economic sectors based on symbolic knowledge (Spencer, 2015, p. 886). Hence, face-to-face interactions are important, and indeed crucial to facilitating interactive learning. In contrast, the creation of analytical and synthetic knowledge is observable and repeatable under the same experimental conditions, and is termed algorithmic knowledge production (Amabile, 1996). These industries are associated more often with 'convergent thinking', aiming to optimize the solution via combining existing knowledge (Spencer, 2015, p. 886). This explains why in Montreal, Toronto and Vancouver, creative and cultural industries are typically found in inner urban areas, where they can "cast a wider net of knowledge and information", whereas science and technology firms are frequently found in suburban areas (Spencer, 2015, p. 886).

Different knowledge bases are also associated with different 'contexts' (Storper, 2009), in turn resulting in different requirements of the communications and exchanges with the local external environment. 'Context' refers to the division of labor and the networks in which the actor situates himself or herself. "The more organizationally internalized the actor's relationships, the more an actor's context is intra-organizational and 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, pp. 13–14). The first case corresponds to science-based firms, which contain intra-firm interactions, whereas the latter describes creative industries, which involve more inter-firm interactions (Spencer, 2015, p. 895). This echoes the finding of Wolke and Zillmer (2010) that high-tech industries, depending more on relatively routine relationships within production systems, tend to concentrate on the peripheries of regions. In contrast, transaction-oriented APS firms value geographical proximity for transferring knowledge with a low transaction cost, thus concentrating in large agglomerations (Münter & Volgmann, 2014, p. 7).

2.4. Knowledge-intensive jobs and spatially-related behaviors

To comprehensively understand the underlying mechanism of the decision-making process among knowledge workers, it is important to take account of the knowledge-intensive tasks conducted in their jobs (their role as individual agents of knowledge creation in knowledge-intensive economies). Knowledge creation has become footloose and is no longer bounded to the physical workplace. Knowledge workers also regard their residence together with their commute path as offering opportunities to find the inspiration that their job requires (Helbrecht, 1998; Schirmer et al., 2014). When knowledge workers choose a residence, the function of maintaining social contacts is as important as, or even more important than the dwelling function. They select locations that match their "social pattern of contact" (Kaplan et al., 2016; Næss, 2006, p. 25). Commute with different modes equate with different degrees of exposure to influences: traveling with active modes or public transport intentionally and unintentionally exposes one to many influences, including fellow commuters and environment (Bissell, 2013, p. 357), whereas sitting in a car involves comparatively less engagement with other commuters and the external environment. Accordingly, when knowledge workers select their commute mode, they also consider the degree of exposure to potential influences along the commute path, aside from travel efficiency. Furthermore, this may even influence their residential location choice (Tran et al., 2016).

Existing studies have generated various findings on the stated or revealed locational preferences of knowledge workers in different contexts and spatial scales. On the one hand, Kotkin (2002) demonstrated that the quality of place matters more than ever before in determining the location decisions of knowledge workers in the United States. On the other hand, Andersen et al. (2010) reported that business climate is regarded as more important than people climate for location choice among the creative class in four Nordic countries. Furthermore, other empirical studies have further investigated the heterogeneous locational preferences among different types of knowledge workers within a specific context. For instance, Musterd (2004) observed that in the urban region of Amsterdam, workers in creative sectors are proportionally more likely to locate in the most urbanized part of the city, while those who work in information, communication and technology tend to orient towards suburban locations. Asheim and Hansen (2009) noticed that in Sweden, the importance of 'people climate' in location choice is greater among workers who primarily use symbolic or analytical knowledge in their occupations, compared to those who mainly use synthetic knowledge. In the United States, Burd (2012) concluded that artists are more likely to migrate to urban areas compared to engineers. Frenkel et al. (2013a) find that workers in financial sectors are more likely to live within the inner ring of the Tel-Aviv metropolitan area compared to workers in high-tech industries. Spencer (2015) reveals that in Canada, creative workers are disproportionally found in dense, mixed-use neighborhoods near the city core, whereas workers in science and high-technology industries usually live in low-density neighborhoods in the suburbs.

We assume that knowledge workers, as basic units of knowledge creation who are analogous to knowledge-intensive firms, might value spatial proximity to varying degrees. Different types of knowledge workers tend to 'orient' themselves differently towards communications with the external environment, and thus would likely display distinct spatially-related choices. We therefore set out to test the following hypothesis: *Symbolic and synthetic APS-workers will tend to reside in central areas and prefer using public transport or active modes to commute, whereas analytical and synthetic high-tech workers will tend to reside in relatively peripheral areas and depend on cars to reach their workplaces*.

3. Methodology

This section will firstly introduce the target group and its categorization. We then introduce the various types of data in our study, followed by the discussion of their limitations and the adjustment to them. Afterwards, we will elaborate our concept of 'central areas'. Finally, the multinomial logistic regression model will be explained.

3.1. Towards a categorization of knowledge workers

Knowledge workers make choices that 'express and nurture' their ability to create knowledge, and their spatially-related behaviors tend to reflect the importance they attach to spatial proximity and their orientation towards encounters with other people (Thierstein, 2016, p. 14). To study knowledge workers' spatially-related choices, we depart from a perspective of knowledge typology employed in specific economic sectors. With respect to the knowledge base that individual knowledge workers primarily use and the employment sector that they work in, we differentiate them into four subgroups. The classification includes workers using analytical knowledge in high-tech industries (abbreviated: analytical high-tech workers), workers using symbolic knowledge in APS sectors (abbreviated: symbolic APS-workers), workers using synthetic knowledge in high-tech industries (abbreviated: synthetic high-tech workers), and workers using synthetic knowledge in APS sectors (abbreviated: synthetic APS-workers). The specific occupations within each group of knowledge workers are presented (Table 1). Since these four groups of knowledge workers appear many times, we refer to them with their abbreviations hitherto.

3.2. Research data

We integrate various types of data in our study. Firstly, to understand the spatio-functional structure of the region, we collect structural statistical data, such as population employment (Bayerisches Landesamt für Statistik, 2015), and the average residential rental cost per square meter for offered accommodation (Immobilien Scout GmbH, 2014). In addition, we also integrate data on knowledge-intensive firms using the Bisnode (2014) database. This data set provides geo-referenced firm-level information on firm locations, sectoral classification and employment. To study individual spatially-related revealed preferences, information on individual residential, workplace locations and commute modes is collected via web-survey. Only individuals who changed residence and/or workplaces within the last three years are invited to participate in the survey.

Secondly, the survey collects positional data, namely the geographical locations of their residences and workplaces, and actual attributes, such as the size and cost of the dwelling. Based on the geographical locations, we also gather relational data by calculating the accumulative accessibility of the workplace, shopping opportunities, as well as leisure and cultural facilities for each residence. Thirdly, apart from the actual choices of residence, workplace and commute mode, we asked respondents to assess the importance of each attribute within these choices using a four-point Likert scale, namely important, rather important, rather unimportant, or unimportant. In the end, 7302 respondents participated in our survey and among them there were 1778 knowledge workers (328 analytical high-tech workers, 242 symbolic APS-workers, 1029 synthetic APS-workers, and 140 synthetic high-tech workers). The socio-demographics and spatially-related choices of knowledge workers are presented in Table A in Appendix A.

The representativeness of respondents needs to be examined since it influences the reliability of our results. Regarding socio-demographic representativeness, people in the age group between 35 and 45 with

Table 1
Classification of knowledge workers into subgroups according to the primary knowledge base and the employment sector. ('*Not applicable*' implies that no occupation exist at the intersection of the primary knowledge base and employment sector).

	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

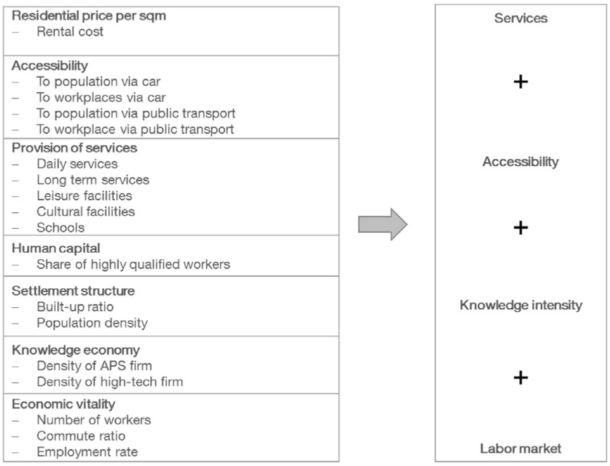

Fig. 2. Aggregation of 18 indicators on seven dimensions to four components with principle component analysis.

employment status are over-represented. This might be due to their frequent usage of the internet. Another possible explanation would be their higher residential mobility due to change of household size and income. Because there is no complete data source on population in the age group between 35 and 45 with employment status and change of residence and/or job during the survey period, we cannot adjust for socio-demographic representativeness. Regarding spatial representativeness, the city of Rosenheim is over-represented, since we have better access to the target group via a cooperation with the city administration in Rosenheim. We apply a spatial expansion factor as the weight for each individual respondent to reduce the disturbance of the spatial over-representativeness. To calculate the spatial expansion factor, we divide the number of people who moved into the municipality in 2014 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 our 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 weighted data after the adjustment does better represent the population who have recently moved.

3.3. *Defining 'central areas' beyond the administrative delimitation*

The metropolitan region of Munich, with a population of 6.0 million in 2015 (Bayerisches Landesamt für Statistik, 2016), locates in Bavaria in Germany. A spatio-functional differentiation of the areas in the region is necessary to better understand individual spatially-related choices, since individuals' choices of workplace, residence, and commute mode are not confined to the territorial-administrative delimitations.

Firstly, we collect 18 indicators on seven dimensions: residential rental cost per square meter, accessibility, provision of services, human capital, settlement structure, knowledge economy, and economy vitality (Fig. 2). The detailed information on each indicator is summarized in Table B in Appendix A. All indicators are available at the scale of association of municipalities ('Gemeindeverband' in German), except the share of highly qualified workers that is available only at the county scale. To guarantee the consistency of the spatial resolution of our data, we assign the same share of highly qualified workers at the county scale to municipalities within the same county. In other words, each municipality 'inherits' the same value from the county that it belongs to. This simple processing is reasonable since the share of highly qualified workers is assumed to be strongly relevant in residential location of knowledge workers, and this share differentiates the current level of human capital among counties. Based on this differentiation, all other 17 indicators will further serve to spatially and functionally categorize individual municipalities.

Secondly, we apply a principle component analysis in SPSS to condense the aforementioned 18 indicators. Four major components, namely services, accessibility, knowledge intensity, and labor market are extracted, and already account for 78.7% of the total variance. The correlation between each component and the original indicator are shown in Table C in Appendix A.

Thirdly, based on these four components, we apply a cluster analysis with the ward method to differentiate the region into five spatio-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 (Fig. 3). The average value of each spatial characteristic of each cluster is recorded in Table D in Appendix A.

Fourthly, the three spatio-functional clusters, '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 have the highest score on at least one of the four components.

Last but not least, considering that residential location is also sensitive to different neighborhood environments within one municipality, only areas that are within less than 1000 m of public transport stations in 'central municipalities' are defined as 'central areas' (red spots in Fig. 4). The remaining areas of the region are defined as 'non-central areas' or 'peripheral areas'. We select public transport stations, including only rail or subway stations, since they are important activity nodes and function as centers of neighborhoods. 1000 m is the maximal distance that a person would normally accept when walking to the public transport station, and is used as the largest radius of the catchment area of the public transport station (Cervero & Day, 2008, p. 14). Since we focus mainly on individual choice between central and peripheral areas, we do not differentiate further between close vicinity (less than 500 m) and secondary vicinity catchment areas (between 500 m and 1000 m). In the end, we are able to identify whether each location is located either within or outside of 'central areas', based on their geographic coordinates.

3.4. *Modeling the joint residential location and commute mode choice*

Regarding the close interrelation between residential location and commute mode choice (Cao, 2015), a joint choice model to combine these two choices is applied. To test our hypothesis, we examine whether the category of knowledge workers explains the joint residential location and commute mode choice. Regarding the choice of residential location and commute mode are discrete choices, we apply a logistic regression. Considering that residential location is differentiated into central and peripheral areas and commute mode is differentiated into car, public transport and active modes, the dependent variable, namely the joint residential location and commute mode choice have six categories: central residence using car to commute, central residence using public transport to commute, central residence using cycling/walking to commute, peripheral residence using car to commute (set as the reference category), peripheral residence using public transport to

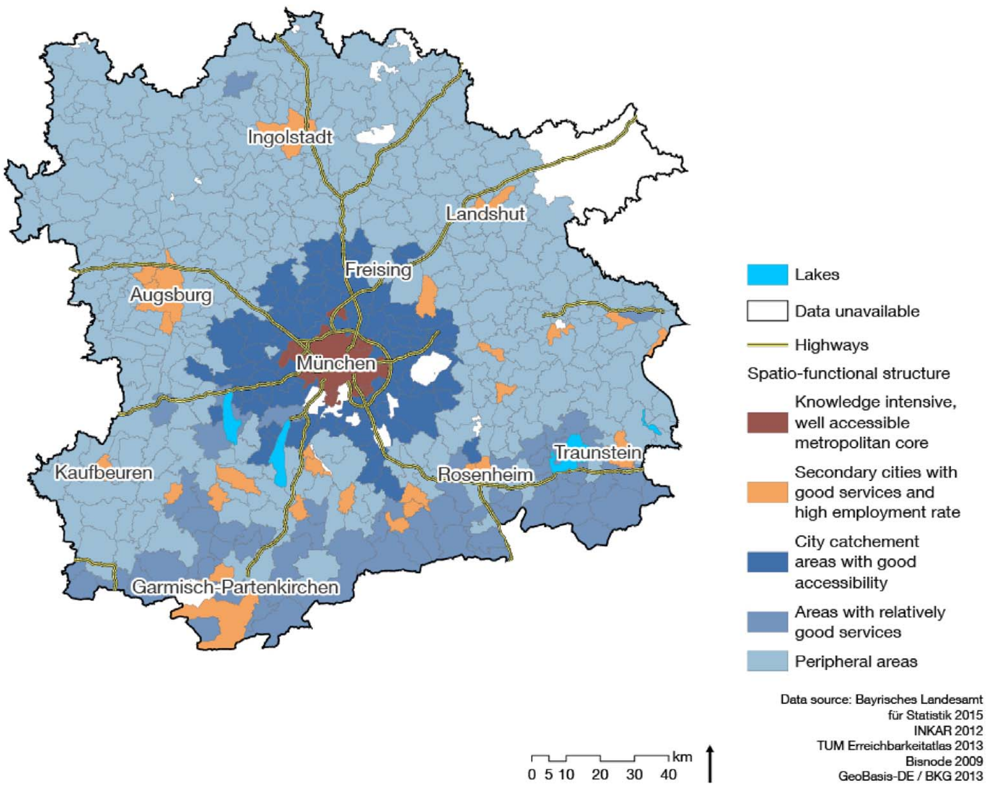

Fig. 3. Spatio-functional structure of the metropolitan region of Munich.

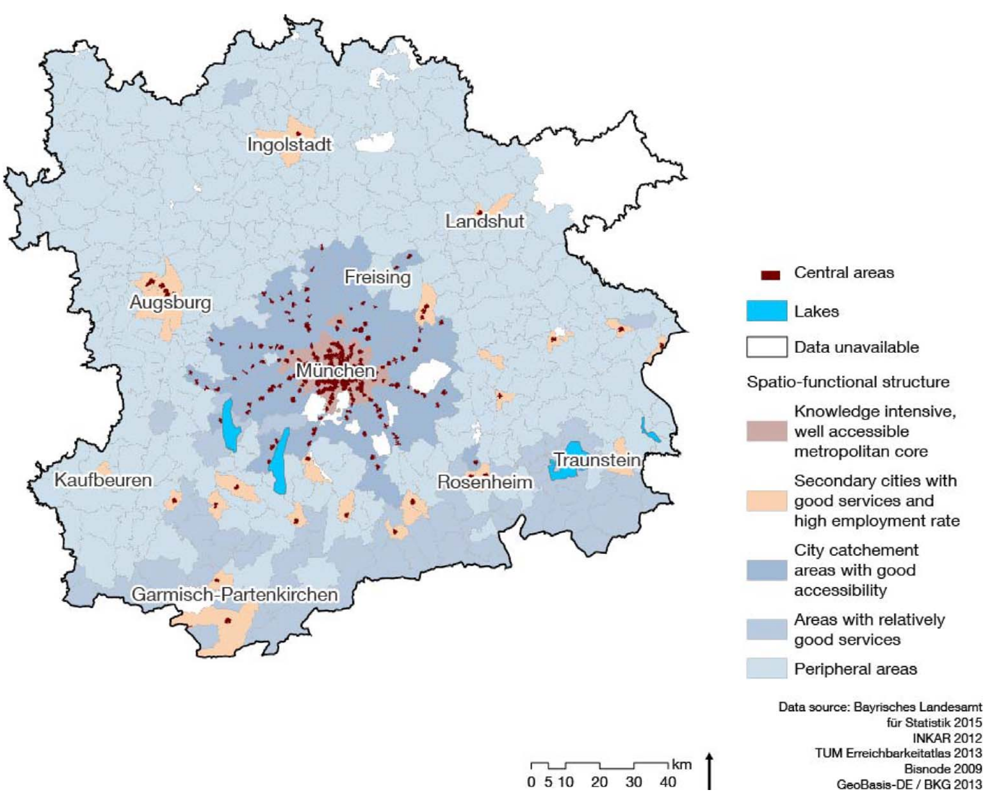

Fig. 4. Distribution of 'central areas' in the metropolitan region of Munich. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

commute, and peripheral residence using cycling/walking to commute. We apply a multinomial logistic regression. 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 (1)).

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

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 certain areas and using a certain commute mode. B_0 is the constant, B_1 to B_n

Table 2
Categories and descriptions of dependent and independent variables in logistic regression.

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%

Independent variables	Categories	Descriptions	Shares
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	< 2000 Euros per month	13.9%
Household type	Single person	Single 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 ownership	Private car	Privately owned car	65.2%
	Company car	Car offered by the company	4.4%
	According to an arrangement, Car sharing	Car is available when it is according to an arrangement, or use car sharing	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 3
Results of the basic model regarding the joint residential location and commute mode choice. (* indicates 0.05 significant level; Odds ratio marked in bold are explained in detail in the text; N = 5142).

Variables	Central residence, commute with car Exp(B)	Central residence, commute with public transport Exp(B)	Central residence, commute with cycling/ walking Exp(B)	Peripheral residence, commute with public transport Exp(B)	Peripheral residence, commute with cycling/ walking 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***
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.

Table 4
Modeling results of the joint residential location and commute mode choice. (* indicates 0.05 significant level; Odds ratio marked in bold are explained in detail in the text; N = 5142).

Variables	Central residence, commute with car Exp(B)	Central residence, commute with public transport Exp(B)	Central residence, commute with cycling/walking Exp(B)	Peripheral residence, commute with public transport Exp(B)	Peripheral residence, commute with cycling/walking 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 an 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
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.

represent the estimation coefficients. X_1 to X_n are independent variables. Firstly, we include household type, gender, education level, car ownership, income level, commute time ratio of traveling with public transport and car, as well as the workplace location as the control variables. Table 2 lists the categories, description, and distribution of the dependent and independent variables. Afterwards, we also include the investigated variable, the category of knowledge workers (analytical high-tech, symbolic APS, synthetic APS, synthetic high-tech workers and other workers). Although we could in principle select any subgroup of knowledge workers as the reference group, synthetic high-tech workers are chosen as the reference group due to the following two considerations: Firstly, existing empirical studies have demonstrated consistent findings on the spatially-related revealed preferences of synthetic high-tech workers (Asheim and Hansen, 2009; Growe, 2010; Spencer, 2015). These workers have the least preference for 'people climate' and concentrate disproportionally in areas with low density. Additionally, within our sample, synthetic high-tech workers attach more importance to car-friendly residential locations but less importance to locations with access to public transport or daily services, compared to all other groups of workers. Some independent variables are directly available from the web-survey, while others need further calculation or transformation. The commute distance, the shortest distance between the workplace and residence along the road network, is calculated using the network analysis in ArcGIS. The commute time with public transport is calculated based on the time schedule provided by the Munich Transport Corporation. The commute time with car is calculated based on open street map. For better interpretation, the 10 categories of net 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 (larger than 4000 Euros per month). Respondents who stated only the importance of car-friendly travel instead of any other transport modes at the residence are defined as individuals with auto affinity. The rest of the individuals are defined as those without auto affinity. A dummy variable of auto affinity is constructed: auto affinity is coded 1; no auto affinity is coded 0.

$$\text{Odds} = \text{Exp}(B_0 + B_1 * X_1 + \ldots + B_n * X_n) \quad (2)$$

The coefficients for the above independent variables are calculated with the maximal likelihood estimation, which predicts the occurrence of the event for each individual case. Based on Formula (1), we are able to calculate the odds of an event (Formula (2)). For categorical variables, $\text{Exp}(B_n)$ is the odds ratio of when X_n is at a certain category compared to the reference category. If B_n is positive, namely $\text{Exp}(B_n)$ is larger than 1, it indicates that the independent variable has a positive influence on the odds of the event. If B_n equals 0, namely $\text{Exp}(B_n)$ equals 1, the independent variable has no effect. If B_n is negative, namely $\text{Exp}(B_n)$ is less than 1, then the independent variable decreases the odds of the event. The estimated coefficients are presented in Table 3 and Table 4.

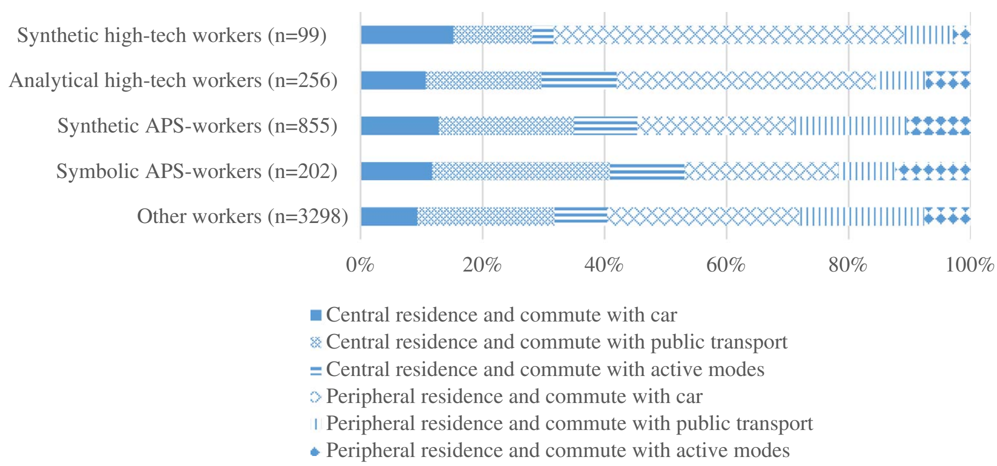

Fig. 5. Residential location and commute mode choice among group of workers.

In the end, 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 E in Appendix A.

4. Findings and discussion

This section we firstly present the results of the descriptive analysis. Secondly, we present the results of the multinomial logistic regression. Lastly, the empirical findings will be discussed.

4.1. Descriptive analysis

Fig. 5 shows the joint residential location and commute mode choice among each group of workers. Almost 60% of synthetic high-tech workers live in peripheral areas and depend on cars to commute. The share of individuals who reside in central areas and use public transport to commute is largest among symbolic APS-workers. One quarter of synthetic APS-workers live in central areas and commute with public transport and another quarter live in peripheral areas and use cars to commute. Analytical high-tech workers are similar to synthetic high-tech workers in terms of location choice, but the share using active modes either in central areas or peripheral areas is much larger than among synthetic high-tech workers.

Their different choices of residential location and commute mode correspond to their different job locations, mobility preference, as well as the mobility resource. Firstly, 76% of symbolic APS-workers' workplaces are located in central areas, whereas the share is only 49% for synthetic high-tech workers (Fig. 6a). Secondly, the different likelihood of living in central areas and commute mode choices among each group of knowledge workers might be directly associated with their different attitudes towards the car (Fig. 6b) and different levels of car ownership (Fig. 6c). These factors must be controlled for when examining the independent influence of the knowledge base.

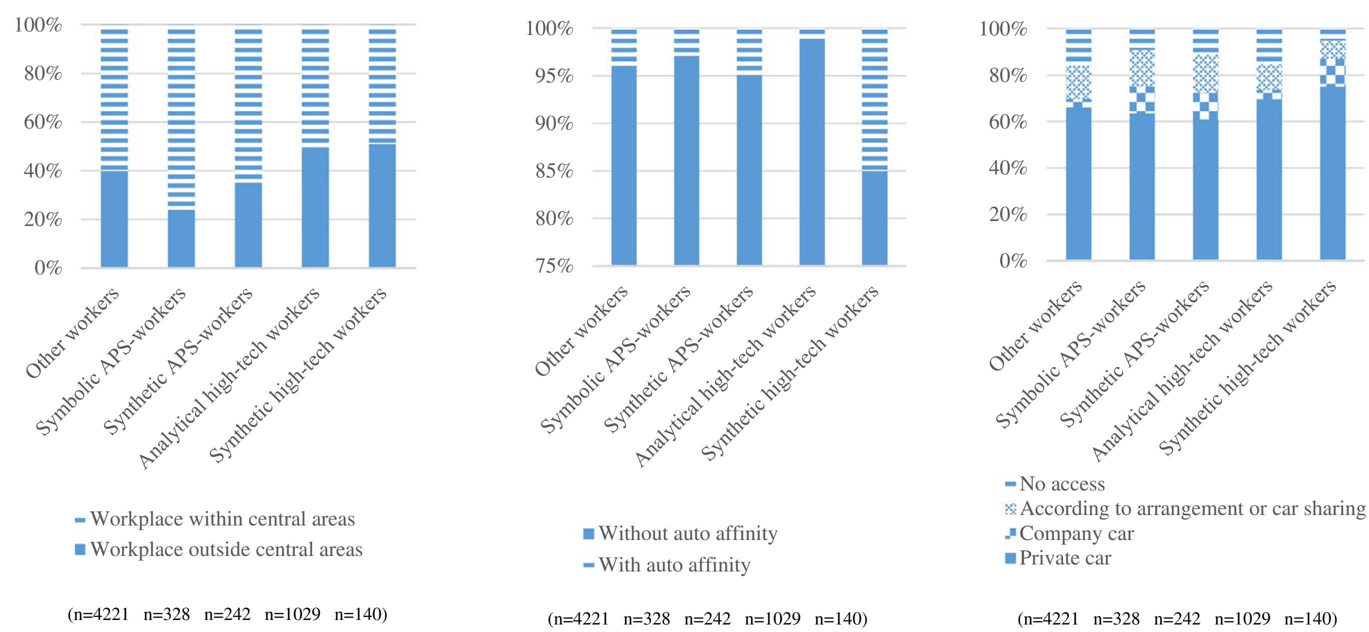

Fig. 6. a. Distribution of workplace locations among each group of workers.
b. Distribution of auto affinity among each group of workers.
c. Distribution of car access among each group of workers.

4.2. Joint residential location and commute mode choice

As shown in Table 3, conventional socio-demographics and spatial structural attributes explain 30.5% of the total variations regarding the joint residential location and commute mode choice. Highest income level both significantly positively associates with living in central areas. Individuals with lowest income level tend to have a smaller likelihood of living in central areas and commuting by cycling or walking, than living in a peripheral location and commuting by car. Single-person households have a larger likelihood of living in central areas and using public transport than family households. 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, compared 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 lies 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 residential location and commute mode choice. Individuals without auto affinity are more likely to live in central areas and commute with public transport or active modes. Even when these individuals live in peripheral locations, they still use public transport or active modes more frequently than cars to reach their workplaces. Lastly, as expected, if one has no access to a car or has access to a car according to an arrangement or car sharing services, the individual 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 use of other modes regardless of the residential location.

Based on the basic model in Table 3, when we further add the categorical variable of knowledge worker group in the model (Table 4), R square increases slightly from 0.305 to 0.324. As expected, compared to synthetic high-tech workers, symbolic APS-workers and synthetic APS-workers are more likely to reside in central areas and commute with public transport, rather than reside in peripheral areas and commute with cars. In addition, compared to synthetic high-tech workers, symbolic APS-workers and synthetic APS-workers are more likely to reside in central areas and commute with active modes rather than reside in peripheral areas and depend on cars to commute. However, it is unexpectedly notable that synthetic APS-workers also show a greater tendency to reside in peripheral areas and commute by public transport or active modes. Analytical high-tech workers show a greater tendency to use active modes and live in peripheral areas than use cars and live in peripheral areas compared to synthetic high-tech workers, which partially contradicts to 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 live in peripheral locations and commute by car among synthetic high-tech workers.

4.3. Discussion

Apart from the well-studied location amenities and the accessibility to workplace, it is essential to consider other aspects in explaining location choices of knowledge workers. Frenkel et al. (2013b) depart from the lifestyle perspective and find that a culturally-oriented lifestyle adds to the possibility of living in central areas. Kaplan et al. (2016) confirm the significance of social networks in the inter-regional migration of knowledge workers. Burger et al. (2014) reveal the different commute patterns between highly qualified workers and less well educated workers in the Randstad region. This study adopts the perspective of the specific knowledge base applied in the occupation to investigate the heterogeneous spatially-related choices among different types of knowledge workers. Within the metropolitan region of Munich, symbolic and synthetic APS-workers have a greater revealed preference for central areas than synthetic high-tech workers, which is consistent with the findings of aforementioned existing studies across different contexts (Asheim and Hansen, 2009; Burd, 2012; Frenkel et al., 2013a; Musterd, 2004; Spencer, 2015). Additionally, this study also confirms that analytical high-tech workers show a greater preference for urban areas than synthetic high-tech workers, but to a lesser extent compared to symbolic or synthetic APS-workers.

Knowledge workers optimize the use of space based in their self-defined utility. Since frequent face-to-face interactions with competitors and customers are valuable opportunities for symbolic APS-workers to interpret and create cultural meanings, they tend to place a high value on locations that support this demand. Within our sample, nearly 45% of symbolic APS-workers mentioned the importance of the attractive locality ('attraktives Ortsbild' in German), whereas the share is only 38% among all other groups of workers. This corresponds to the finding that 30% of symbolic APS-workers visit cultural and gastronomic facilities which facilitate unplanned informal exchanges between one and three times per week. Indeed, we observe that symbolic APS-workers disproportionally reside in central areas that are close to the poles of knowledge exchanges (Brake, 2015). Synthetic APS-workers try to maximize accessibility to existing and potential suppliers and customers. Central areas with a maximal accessibility would be preferable. Nevertheless, if this preference cannot be realized, the option of a peripheral residential location with good accessibility via public transport is also acceptable. This is similar to the finding of van Oort et al. (2003) that the preference for the proximity to the city center can be substituted by a nearby shopping center among workers active in the information and telecommunication technology (ICT) industries. There is no significant difference regarding the possibility of living in central or peripheral areas between analytical and synthetic high-tech workers. The possible reasons might be that on the one hand, the smaller sensitivity of analytical high-tech workers to spatial separation will 'push' them to the suburban areas, compared to synthetic high-tech workers. The quality and facilities of the dwelling might be the prime consideration in their residential choice. On the other hand, synthetic high-tech workers are more likely to purchase a residence, which is relatively cheaper in the suburban areas, especially in the Munich region with its tight housing market.

Different residential locations associate closely with the choice of commute mode. For instance, the less frequent usage of public transport among analytical and synthetic high-tech workers is attributable to their relatively peripheral residential location choices. Furthermore, since the commute path is also integrated into the job-housing matrix, the 'atmosphere' or the environment surrounding the residence, workplace and along the commute path are similar in type. Our results demonstrate that centrally located residences are in many cases coupled to car-free commuting among symbolic APS-workers, whereas relatively peripherally located residences are frequently coupled with car commute among synthetic high-tech workers. We obtain a finding similar to the finding of Frenkel et al. (2014) that the availability of a company car will encourage the use of cars as the commute mode among knowledge workers. Nevertheless, even when the difference in the availability of company cars is considered, the distinctly different distribution of commute modes between analytical and synthetic high-tech workers would still be attributable to other factors. One of the reasons is that analytical high-tech workers' larger share of active commute modes is due to their greater share of short commute distance (perhaps related to their relatively longer working hours). In addition, analytical thinking is less convergent than synthetic knowledge creation and is independent of a fixed workplace compared to synthetic knowledge creation. Hence, analytical high-tech workers prefer to commute by 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 (2002) observation that "the world is unfolding around you" when cycling or walking (Florida, 2002, p. 180), so analytical high-tech workers can also make full use of the commute time to be inspired by surrounding people and events (Florida, 2002, p. 180).

5. Conclusions

The influence of knowledge base, knowledge production mode and the corresponding context on spatial patterns not only applies to knowledge-intensive firms but very probably also to knowledge workers, since they are the basic units in the exchange and creation of knowledge. Social networks are not only important in regional migration (Kaplan et al., 2016), they even associate with different weights attached to the specific locational attributes within a region. Symbolic APS-workers associated with heuristic knowledge production maximize their exposure to potential influences as well as informal interactions with other like-minded people. In contrast, synthetic high-tech workers associated with algorithmic knowledge production tend to simplify their communication with the external environment.

To summarize, the type of knowledge base that an individual knowledge worker uses on the job to some extent connects to the revealed preference for residential location and commute mode. The empirical results partially confirm our hypothesis. As predicted in the hypothesis, symbolic APS-workers do indeed show a greater likelihood of 'inhabiting' heterogeneous and networked environments: they live in central areas and use car-free modes to reach their workplaces. In contrast, synthetic high-tech workers tend to 'retreat' to homogeneous and detached environments, residing in relatively peripheral areas and depend on cars to commute. However, synthetic APS-workers also show a certain tendency to live in peripheral areas and commute with public transport. Analytical high-tech workers also show a greater tendency to commute with active modes than do synthetic high-tech workers. We conclude that the spatially-related preferences revealed among each group of knowledge workers do not form a binary division of behavioral prototype as mentioned in our hypothesis. Instead, within our sample, they form a spatial-behavioral continuum with symbolic APS-workers (13.6% of total KW) and synthetic high-tech workers (7.9% of total KW) representing the two poles, with synthetic APS-workers (60.1% of total KW) and analytical high-tech workers (18.4% of total KW) positioned between them on the continuum. In addition, the spatially-related choices of synthetic APS-workers are more similar to those of symbolic APS-workers, whereas the spatially-related choices of analytical high-tech workers are more similar to those of synthetic high-tech workers.

This study provides several implications for policy-makers and urban planners regarding the attraction and retention of knowledge workers within the metropolitan region of Munich. First of all, while 'people climate' or the living environment of a region should continue to be cultivated, it is also recommended that 'business climate', work opportunities and the accessibility to the location of employment be given equal or even more attention in order to encourage knowledge workers to migrate to the region. Secondly, policies and spatial planning must recognize the heterogeneous locational preferences among different types of knowledge workers and avoid the mere emphasis on cultural facilities and amenities near the city center. In other words, the provision of alternative residential units with varied living environments and transport options should be promoted to satisfy various preferences among all types of knowledge workers. Lastly, the interrelation between residential location and commute mode choice among knowledge workers indicates the need of further investments in improving public transport and cycling/walking infrastructures in dense urban areas. Equally important, good public transport links in suburban residential neighborhoods should be enhanced to guarantee reasonable mobility costs and good accessibility for synthetic APS-workers—the largest group of knowledge workers in the metropolitan region of Munich.

Future work should aim to explore the direct linkage between the interaction patterns of each knowledge base and the joint residential location and commute mode choice. We also suggest employing qualitative methods to trace the more specific motivations underlying these interrelated spatially-related choices. In addition, data concerning the lifestyle, the type of social networks and even the personality of the individual knowledge worker might also be helpful in fully understanding these spatially-related behaviors. Lastly, given that the analytical-synthetic-symbolic knowledge typology refers to ideal types but that in reality knowledge workers usually employ more than one knowledge base in their jobs, this classification of knowledge workers may oversimplify their knowledge-intensive job-related tasks. Hence, the integration of several knowledge bases to comprehend their spatially-related behavior would profit from further in-depth analysis.

Appendix A

Table A
Socio-demographics and spatial choices of knowledge workers in the survey.

Variables	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 B
Detailed information of indicators included in the cluster analysis.

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 C
Rotated component matrix with coefficients between each indicator and the component. (Coefficients less than 0.40 are not displayed.)

Indicators	Components			
	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 D
Mean component score and indicator value of each spatio-functional cluster. (Highest score are marked in bold).

Components	Mean value for each spatio-functional cluster				
	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 m^2)	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	1,460,480.76	1,176,145.79	479,637.75	549,351.92	629,380.50
Gravitational accessibility of potential workplaces with private motorized transport	655,141.76	506,519.17	191,612.61	218,893.92	254,046.41
Gravitational accessibility of potential workplaces with private motorized transport	1,059,399.22	588,996.77	161,052.25	171,606.69	324,622.31
Gravitational accessibility of potential workplaces with private motorized transport	521,165.65	279,902.74	68,715.69	76,343.79	143,070.29

Table E
Robustness test of multinomial logistic regression models for the joint residential location and commute mode choice. (* indicates 0.05 significant level).

Variables	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		
		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)															
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)															
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)															
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)															
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)															
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															
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)															
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)															
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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