Residential self-selection and travel mode use in a new inner-city development neighbourhood in Berlin

Julia Jarass and Joachim Scheiner

Dr. Julia Jarass, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Verkehrsforschung, Mobilität und Urbane Entwicklung, Rutherfordstraße 2, D-12489 Berlin
phone ++49-30-67055-7927, fax ++49-30-67055-283, e-mail Julia.Jarass@dlr.de

Prof. Dr. Joachim Scheiner, Technische Universität Dortmund, Faculty of Spatial Planning, Department of Transport Planning, 44227 Dortmund, Germany
phone ++49-231-755-4822, fax ++49-231-755-2269, e-mail joachim.scheiner@tu-dortmund.de

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Abstract: The purpose of this study is to analyse the effects of residential and travel preferences on mode use in a new inner-city development in Berlin. In contrast to the majority of related studies, we consider these preferences in a more holistic way by grouping residents into clus-ters. The kind of inner-city neighbourhood we studied particularly attracts families and cou-ples who are affluent and have high levels of car ownership. However, a comparison of resi-dents' mode choice with that of the general population of inner and outer Berlin shows that this kind of inner-city neighbourhood encourages even those households who are known to prefer driving to use modes other than the car. Moreover, we found variety in mode use which could be traced to the variation in reasons for residential choice (as an outcome of res-idential and travel preferences). This underlines the fact that preferences have a strong effect on travel behaviour, even in a homogenous neighbourhood. Overall, the study suggests that new inner-city development neighbourhoods with a variety of housing types provide oppor-tunities for sustainable daily mobility. At the same time the study area could have been better adapted to the various preferences of its future residents – for example, by reducing the num-ber of parking spaces to further stimulate use of sustainable modes of transport.

Keywords: Residential self-selection; Travel mode use; New inner-city development; Residen-tial preferences

1 Introduction

The concept of residential self-selection (RSS) effects on travel behaviour has emerged as a major field of research in transport studies over the past two decades. Put briefly, this research argues that geographical differences in travel behaviour are not (or not only) caused by the travel opportunities provided by the built environment in which someone lives, but are to some extent motivated by households' residential choices based on their residential and travel preferences and other social and personal characteristics, which results in sociospatial/attitudinal segregation of population groups (Cao et al., 2009; Mokhtarian and Cao, 2008). This debate did not, however, emerge from psychology or sociology, but from the land-use/transport discipline. It was, and still is, driven mainly by planning studies, and it seeks to establish that some of the observed spatial differences in travelling may in fact be caused by attributes of the spatial context in which people live, and hence may be affected by urban planning decisions.

While up to the 1990s RSS was controlled for by including sociodemographic variables in travel behaviour studies, the paper by Kitamura et al. (1997) marked a new departure, being one of the earliest efforts to simultaneously control for neighbourhood and travel preferences. Since then, a bulk of empirical, methodological and theoretical research has contributed to the considerable importance that the field has today.

Most studies in this field focus on mode choice, which sounds natural as it appears more intuitive that different individuals have distinct preferences for different modes, while it seems less intuitive that people would have preferences relating to travelling certain distances, travel time budgets, or levels of trip chaining – although these ideas are not actually very wide of the mark. As travel distance and time are typically conceived of as cost factors, one may well argue that travel-related residential self-selection may refer to travel distances or willingness to travel (Scheiner, 2010; Naess, 2014; Elldér, 2014; De Vos and Witlox, 2016).

This paper adds another empirical facet to the field. While studying mode use – as with most other related research – it is based on a survey in a newly established area of Alter Schlachthof in the inner-city area of Berlin. This area is relatively homogeneous in terms of population structure, and the majority of its residents moved into the area no more than a few years prior to the survey. It can thus be seen that self-selection has actually taken place shortly before the survey. Consequently, we expect only weak effects of sociodemographics on mode use (because of homogeneity – for example, Ettema and Nieuwenhuis (2017) find very limited effects of sociodemographics on car use in a study of those recently moving into transit-oriented developments (TODs) in the Netherlands), but variety in mode use owing to various reasons for self-selecting (as an outcome of preferences). In other words, our study allows for a more nuanced understanding by providing evidence for the heterogeneity of residential and travel preferences of people choosing the same neighbourhood, and the consequences this heterogeneity has for travel, while most studies in the field place emphasis on travel preferences. Thus, this study focuses on the identification and characterisation of resident groups who, for different reasons, have decided to move into the same residential neighbourhood and the question to what extent they differ concerning their daily mode use.

To assess the combined influence on mode use of a variety of preferences, we consider residential preferences in a more holistic way by grouping residents into clusters. On the other hand, we do not look at the role of RSS for travel relative to effects of the built environment, which is the focus of most related research, as we do not compare different study areas.

A second point that makes this study unique is that the area is a major example of a planned attempt to support family re-urbanisation in Germany – that is to say, it was an explicit attempt to attract middle- and upper-class families to reside there, who were otherwise expected to move into suburban environments (see Frank, in print, on similar developments elsewhere). Hence, by comparing residents' mode choice with that of the general population of inner and outer Berlin, the study allows us to find out whether, and if so to what extent, an inner-city neighbourhood encourages even affluent households with high levels of car ownership to use modes other than the car. This would encourage policies on urban form aimed at reducing car use even among those population groups who are typically associated with high levels of driving: middle-aged, high income households with children owning a car (or two).This paper is structured as follows. Section 2 briefly introduces the current state of research on urban form, residential self-selection and travel behaviour. This is followed in Section 3 by an introduction to the study area, the data and methods. Subsequently the results are presented in Section 4. Section 5 discusses the results and draws some conclusions for policy and research.

2 State of the Research

Because of the multitude of RSS–travel studies – i.e. studies that link travel behaviour with residential self-selection -, this section cannot provide an exhaustive overview (see Cao et al. (2009), Bohte et al. (2009), Abreu e Silva (2014) and Lin et al. (2017) for excellent reviews, and the special issues of Transport Reviews 29(3) and Journal of Transport and Land Use 7(3) for in-depth studies. Cao and Chatman (2015) contains an up-to-date theoretical discussion).

To provide the background for the RSS–travel debate, it is important to note that the majority of studies on the effects of land use on transport take a cross-sectional approach, and tend to rely on correlational structures to propose cause–impact effects, despite the fact that the potential biases of such approaches have long been recognised. The majority of RSS–travel studies also use cross-sectional data, but in theoretical terms they are process-oriented. This is because they typically assume that preferences precede residential choice and, hence, the built environment found at the residence, which in turn precedes travel behaviour. Accordingly, the built environment at the residence is considered endogenous to preferences. ‘Preferences’ in this research is a term with a broad scope, and can refer to attributes of the residence, neighbourhood, and residential location (in brief: residential preferences), and also to travel modes, accessibility and more general features of travelling (travel preferences) (Scheiner, 2014). Residential preferences have been found to be closely connected with travel mode preferences and with preferences for certain social environments, such as heterogeneous or homogeneous populations, more or less privacy etc. (Liao et al., 2015).

Although many scholars note that the interrelations between preferences on the one hand, and travel behaviour and the built environment on the other, *may* not necessarily be unidirectional – i.e. *may* include reverse relationships – only few strongly argue for (Naess, 2009) or empirically account for (Bohte, 2010, p. 81–109, Kroesen et al., 2017) such reverse relationships, although the issue of causality between attitudes and behaviour has been recognised by transportation researchers decades ago (Tardiff, 1977). Using data collected in the Netherlands, Bohte concludes that “travel behaviour and built environment characteristics (residential location choice) have a greater effect on travel-related attitudes than vice versa” (ibid., 102), although it must be highlighted that her models are based on cross-sectional data. Kroesen et al. (2017) provide direct evidence that mode use affects mode attitudes more strongly than vice versa by using cross-lagged panel models. Choocharukul et al. (2008) use data from Thailand to show that travel preferences significantly affect residential preferences. They also trace car use preferences back to a sense of moral obligation to reduce car use. These studies suggest complex interrelationships between travel preferences, residential preferences, residential choice, the built environment and actual travel behaviour.

RSS–travel studies use a variety of methodological approaches (Mokhtarian and Cao, 2008; Bohte, 2009; Van Herick and Mokhtarian, 2015), including asking directly for the impact of preferences, statistically controlling for preferences, using instrumental variables to model the built environment at the residence, using sample selection models, using propensity score models and/or other joint models with multiple equations (either discrete choice or structural equations models (SEMs)), and using longitudinal designs (looking at travel behaviour before and after relocation) .

RSS–travel studies share a common understanding that RSS can be traced back to two factors: sociodemographics and preferences (Mokhtarian and Cao, 2008). While preferences (also called ‘taste variations’) reflect the way in which households or individuals wish to live, sociodemographics may also to some extent reflect preferences, but they predominantly represent ‘hard’ constraints that households face in terms of income, social roles, age group, or ethnic background – i.e. ‘givens’.

We now review some empirical studies. In line with our empirical work we focus on (a) studies conducted in newly developed residential areas and/or sampling recent movers, (b) studies conducted in inner-city, high-density, or transit-oriented development areas and (c) cross-sectional studies that use statistical controls of preferences, either as dimensions or groups (clusters). Further, our review has (d) a certain bias towards European studies, as these include a variety of travel cultures, while the (more dominating) North American research tends to focus on a homogeneous car culture.

Scheiner and Holz-Rau (2007) apply SEMs to data from the Cologne region of Germany. The models simultaneously include the effects on modal shares and vehicle kilometres travelled of: sociodemographics, lifestyles, residential preferences, and the built environment at the residence. They find that lifestyles have limited direct effects on travel, but do affect residential preferences and residential choice, which in turn both affect travel behaviour.

Naess (2009) uses a mix of regression modelling, bivariate analysis and qualitative data collected in Copenhagen, Denmark and Hangzhou, China, as well as strong theoretical reasoning to argue that studies controlling for car ownership and preferences as exogenous control variables tend to underestimate the effects of the built environment on travel behaviour, as car ownership and preferences are themselves affected by the built environment someone lives in.

Abreu e Silva (2014) uses SEMs to analyse data from Lisbon. He models the effects of the built environment on various measures of travel behaviour, including commuting distance, car ownership, number of trips by mode and trip scheduling. He also finds a number of significant effects of sociodemographics and attitudes towards private and public transport modes.

Noland and DiPetrillo (2015) study the frequency of use of various modes in TODs in New Jersey using SEMs. While controlling for preferences, they find that those living near public transport stations use public transport and walk more often than those living at a distance from the nearest station. For driving it is the other way round.

Langlois et al. (2015) add another facet by including reasons for moving. They conduct a survey in seven TODs in the USA and Canada to study mode *switches* by respondents after their move to a TOD. Results based on multinomial logistic regressions show that TOD newcomers switch to more sustainable modes for leisure trips, but not for work and shopping trips. RSS plays a significant role in terms of the effects of reasons for moving in. For example, those who moved to the TOD explicitly because they wanted to live closer to public transport are more likely to switch to a more sustainable mode.

Ettema and Nieuwenhuis (2017) distinguish between general travel attitudes which they consider to be “more passive” (and less relevant for residential choice), and travel considerations as a deliberate reason for choice of residential location. They use a survey among recent movers to one of three TODs in the Netherlands to test whether the reason for choice of location has an additional effect on mode use over and above the effects of general travel attitudes. They find that both general travel attitudes and travel-related location choice reasons affect mode choice, the latter being particularly pronounced for train travel. However, they also find that the associations between travel attitudes and residential choice are weak, and even the associations between travel attitudes and travel as a reason for choice of location are only moderate. In other words, there is no strong travel sorting mechanism in residential choice. This confirms earlier research on mismatch between preferences and chosen location (Schwanen and Mokhtarian, 2004).

This is supported by Liao et al. (2015). They perform a latent class analysis with data collected in Utah, USA. Even though this is a strongly car-oriented setting, about 40% of respondents were found to strongly prefer compact, walkable and public-transport-friendly neighbourhoods. Their results also show that preferences are heterogeneous within compact developments.

Kamruzzaman et al. (2015) use an approach based on Schwanen and Mokhtarian (2004) and De Vos et al. (2012) to study the commuting mode choice of residents in TODs and their respective ‘evil twins’ (transit-adjacent developments) in Brisbane, Australia. While not being limited to recent movers, the study finds that travel preferences and reasons for choosing the residence significantly affect mode choice, similarly to Ettema and Nieuwenhuis (2017). Similarly, Thérèse et al. (2010) study the commuting mode choice of car-owning residents in inner-urban high-density areas of Brisbane. Results confirm that travel-related reasons for relocating are positively associated with the mode given as the reason for relocating.

Summarising the literature, there is considerable evidence for the relevance to travel behaviour of both travel preferences and residential preferences, while at the same time the built environment at the residence also affects travel behaviour. Some studies distinguish between more general travel and residential preferences, and (perhaps more robust) actual reasons for choice of location (or for moving). These reasons are measured either as separate dummies (Langlois et al., 2015), factors (Kamruzzaman et al., 2015) or Likert scales (Ettema and Nieuwenhuis, 2017). Preferences are generally measured as separate dimensions, which permits a distinction to be made between the effects of different types of preferences. On the other hand, residential preferences have been found to be closely connected with travel mode preferences and with preferences for certain social environments (Liao et al., 2015). This favours a holistic understanding of preferences, for example by grouping respondents into clusters based on the total set of preferences measured.

This grouping is rarely done in RSS–travel studies, but Ohnmacht et al. (2009) are an example. Although not explicitly referring to RSS, their study can be interpreted this way. They cluster Swiss respondents into ‘leisure mobility style’ groups based on their travel and leisure preferences, thus contributing to a holistic understanding of individual ‘mobility orientations’, and they show that these styles contribute to explaining leisure travel behaviour, while sociodemographics and urban form are controlled for.

In the following section, we present our empirical contribution to this research. In accordance with the literature, we assume unidirectional effects of residential preferences, sociodemographics, mobility options and urban form on travel mode use. However, in contrast to most other studies in the field, but in accordance with Ohnmacht et al. (2009), we consider preferences in a more holistic way by grouping travellers into clusters. Another specific of our study is that it focuses on a socioeconomically homogeneous, newly developed inner-city area in Berlin. Owing to the short duration of residence of our respondents, their RSS has actually been expressed a relatively short time before the survey.

3 Methods

3.1 Research area and data

In 2012, a survey was conducted in the area of Alter Schlachthof, Berlin. The research area has a unique character: although located at the border of the inner-city districts, it combines both urban and suburban characteristics within the same neighbourhood (see Frank, in print). Most studies analyse RSS in different sets of neighbourhoods, such as urban neighbourhoods versus suburban neighbourhoods (e.g. De Vos et al. (2012), Kamruzzaman et al. (2015), Schwanen and Mokhtarian (2004, 2005), Handy et al. (2005). By analysing residential preferences within the same area with a variety of urban and suburban characteristics, we also expect a variety of residential preferences.

Berlin is a something of a special case in Germany, having a very low car ownership rate, an extremely well-developed public transport system, and a dense, small-scale distribution of shopping facilities, services and leisure opportunities in most residential areas, particularly in the inner city. The research area is located in the east of the inner city and covers an area of about 58 hectares. It accommodates different types of apartment buildings and terraced houses with gardens (Figure 1).

Figure 1: Terraced houses and apartment building in Alter Schlachthof (Source: Jarass 2013)

Still under construction, the area is characterised by a lower-density urban structure while the surrounding neighbourhood is a densely populated area with mixed land-use. Though Alter Schlachthof is mainly residential, there are shopping facilities located within walking distance. The area is well connected to several public transport facilities: light rail, tramway, bus and underground stations can be found in proximity to Alter Schlachthof. Despite this, the area is fully equipped with private and public parking spaces.

In October of 2012, about 700 households were contacted and asked to participate in a paper-based survey. Since the research area had just been established a few years previously, the sample includes only residents who had recently moved in (87% had done so within five years prior to the survey). The 12-page questionnaire was personally distributed to, and later collected from, the households (the response rate was 46%). In each case one household member aged 18 or older was asked to fill in the questionnaire. The dataset contains detailed information about a total of 317 residents, their household structure, the decision process behind their residential relocation, and their daily travel behaviour. Table 1 sets out the sociodemographic and socioeconomic characteristics in Alter Schlachthof, separately for the area of terraced houses and the area of apartment buildings.

Table 1: Sociodemographic and economic characteristics of the respondents (Data: Alter Schlachthof 2012 and "Mobility in Cities – SrV 2008", sample Berlin, Senatsverwaltung für Stadtentwicklung und Umwelt Berlin, Abteilung Verkehr)

		Alter Schlachthof		Inner Berlin	Outer Berlin
		Area of terraced houses	Area of apartment buildings		
Percentage female (>17 years)		62%	50%	49%	52%
Mean age (years) of adult residents (>17 years)		41	47	45	50
Percentage of adult residents (>17 years) with general qualification for university entrance		90%	66%	64%	47%
Percentage of employed residents (>17 and <65 years)		88%	86%	66%	64%
Percentage split of household size (members)	1	3%	20%	62%	47%
	2	20%	42%	23%	34%
	3	26%	25%	8%	11%
	4+	51%	12%	7%	8%
Mean equivalent[1] monthly net household income (euros)		2,426	2,121	1,399	1,405
Sample size		178	139	11,131 persons/ 6,834 households	21,139 persons/ 11,472 households

Note: Data for inner and outer Berlin is weighted.

We use the data from the survey "Mobility in cities – SrV 2008" (system of representative travel behaviour surveys) to compare the sample with the average population in inner and outer Berlin on the statistical area level (see Figure 2). It is possible that SrV 2008 is not 100% compatible with our survey, owing to differences in data collection (e.g. collection methods, time period). Moreover, in our survey only one member (>17 years) of each household participated, whereas in SrV 2008 all members of a household were asked to participate. When comparing both surveys on the personal level we therefore take only residents 18 and over into account.

Generally speaking, the survey respondents differ demographically from the population of inner and outer Berlin. Moreover, there are also differences between the residents living in the terraced houses and those living in the apartment buildings. In the area of terraced houses, more women (62%) than men participated in the survey, whereas in the area of apartment buildings the split between men and women is equal. The responding residents of the area of terraced houses are slightly younger (41 years on average) than the responding residents living in the area of apartment buildings (47 years). In comparison, the population of Berlin is of average age

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[1] Using the equivalent income, the income situation of households can be displayed depending on the household size and structure. According to the proposed OECD scale of Hagenaars, De Vos and Zaidi, the first adult in a household is weighted with 1, each additional person over 14 years with 0.5, and children under 14 years with 0.3 (Anyaegbu 2010: 50).

Figure 2: Location of the research area Alter Schlachthof within Berlin (Source: Jarass 2018; Data: Senatsverwaltung für Stadtentwicklung und Umwelt 2009)

45 years in inner Berlin, and 50 years in outer Berlin. Moreover, the sampled residents of the area of terraced houses possess a higher level of education than those from the area of apartment buildings; however, the proportion of employed residents is more or less equal in the two subareas, but in both cases higher than is found in the inner or the outer city. The household size in the research area differs markedly from inner and outer Berlin. As intended by planners, Alter Schlachthof seems to have particularly attracted multiple-person households. Taking a closer look at the household structure, it turns out that most of the residents in the area of terraced houses live in a family (75% of those who responded) and more of the residents living in an apartment building live as a couple (42%) than in any other arrangement. This household structure is in sharp contrast to the composition of households in the inner city, where the majority of the households are single-person (62%). The sampled households dispose of an equivalent monthly net income of about €2,400 for those in the terraced houses, and €2,100 for those in the apartment buildings, which is distinctly more than in inner or outer Berlin as a whole (where monthly household net income is about €1,400).

A large majority of residents moved from other inner-city areas within Berlin to this newly developed neighbourhood. A total of 67% moved from neighbourhoods within inner Berlin, and 16% previously lived elsewhere in Berlin. Less than 1% came from the hinterland of Berlin. The proportion moving in from all other regions was 17%. When asked for alternative residential options considered during their search for accommodation, 56% of the respondents living in a terraced house and 71% of those living in an apartment building stated that they had been looking for locations only within Berlin's inner city.

3.2 Modelling approach

To study the influence of residential and travel preferences, mobility options and sociodemographics on mode use, we apply generalised linear regression models for each transport mode (walking, cycling, public transport and car). As response variables, we use the share of a mode, which has bounded values between 0 and 1 (see 3.3.2 for further explanation of mode use). Thus, we need an estimation method that allows the estimation of fractional values with a high proportion of extreme values. We follow Papke and Wooldridge (1996) who suggest the quasi-likelihood estimation method for fractional response data, which is a specialisation of the generalised linear model (see also Gourieroux, Monfort and Trognon, 1984; McCullagh and Nelder, 1989). This approach is more flexible, robust and subject to fewer restrictions than, for example, the Tobit model which requires a normally distributed response variable (Ramalho/ Ramalho/ Murteira 2011: 22). We use the ‘frm’ (fractional regression models) package in R statistics which is developed by Ramalho et al. (2011). It is based on a logit transformation for the response variables (for similar approaches see Heinen and Chatterjee, 2015, Song et al., 2013).

When developing the models, we remove statistically insignificant explanatory variables from the final models in order to achieve parsimonious models. It needs to be pointed out that the approach chosen assumes that residential preferences and sociodemographics precede choice of location and daily travel behaviour. However, it is possible that there is a feedback mechanism whereby preferences are modified owing to learning processes induced by experiences had with actual travel behaviour or the built environment (Naess, 2014; Bohte, 2010; Tardiff, 1977; Dobson et al., 1978). In our case, such adaptation of preferences should be more limited than in most other studies, as we focus on new residents. Still, 13% of our respondents had been living in Alter Schlachthof for more than five years prior to the survey.

3.3 Variables

In the following subsections we describe the measurement of key variables. Table 2 shows descriptives of all variables used in the regression models.

Table 2: Descriptives of variables used in the regression models (Data: Alter Schlachthof 2012)

	Mean	Standard deviation	Min	Max	Sample size
Sociodemographics and mobility options					
Age (in years)	43.3	13.8	18.0	93.0	310
Number of bicycles per person (>6 years)	0.9	0.8	0.0	7.5	305
Number of cars per household	1.0	0.6	0.0	4.0	309
Mode use					
Walking	0.26	0.23	0.00	1.00	315
Cycling	0.21	0.27	0.00	1.00	315
Public transport	0.25	0.26	0.00	1.00	315
Car	0.26	0.29	0.00	1.00	315

	Percentage	Sample size
Household type		
Single household	10.9%	34
Couple	29.8%	93

Family	57.4%	179
Other household type	1.9%	6
Occupation type		
Full-time employed	59.5%	185
Part-time employed	19.9%	62
Unemployed / other occupation	20.5%	64
Residential preference clusters		
Child-friendly living	13.3%	32
Car-oriented living	28.6%	69
Urban living	12.0%	29
Homeowner living	18.7%	45
Sophisticated living	27.4%	66
Sociodemographics and mobility options		
Child (<12 years) in household	50.2%	155
Season ticket (annual/monthly) for public transport	45.2%	141

3.3.1 Residential and travel preferences

The survey includes 23 statements of preferences concerning travel and residential characteristics, recorded as answers to the question "How important were the following attributes when you looked for your future residential location?" The residents were asked to indicate their preferences on a five-point Likert scale from 1 (not important) to 5 (very important). Since 87% of the residents had been living in Alter Schlachthof for no longer than five years, we assume errors of recollection to be small in number. We apply a principal component analysis (PCA) with varimax rotation in order to reduce the number of neighbourhood and housing characteristics into uncorrelated factors. This approach is suitable to prepare the data for the subsequent cluster analysis which demands uncorrelated input variables to group the residents into homogenous groups (for similar approaches see Klinger et al. 2013: 24, De Vos et al. 2016: 782). Owing to low correlations and low variance (Field, 2013, p. 685), we do not include the following items in the PCA: *central location, accessibility of public transport, proximity to work/education, proximity to friends, facilities for the elderly, bigger apartment, well-designed apartment*. The number of factors is determined based on the scree plot, the criterion {all eigenvalues larger than one} and the interpretability of the factors. With a variance of 72% explained, the following five factors are extracted: *privacy and property, safety and neatness, child-friendly neighbourhood, land-use mix, car-friendly infrastructure* (see Table 3). The reliability analysis of the scales identifies a Cronbach's α varying from 0.74 to 0.90 among the five factors, which shows that the extracted factors can be considered consistent (a value of 0.7 or above being generally considered to represent acceptable scale reliability).

The factor scores are used to group the residents according to their residential preferences by applying a cluster analysis. In doing so, we try to map the individual preference spectrum of each person in a holistic way, instead of analysing preference dimensions separately as if they were unrelated. By clustering the population according to their residential preferences it is, for example, possible to distinguish two persons who agree on the relevance of specific housing characteristics but have different views regarding the transport infrastructure. To achieve the best possible classification we apply a two-step process (Janssen/Laatz, 2013, p. 492). First, we conduct a hierarchical cluster analysis by using the Ward method to determine the optimal num-

Table 3: Factor loadings for residential preferences (Data: Alter Schlachthof 2012)

Item	Factor loadings				
	Privacy and property	**Safety and neatness**	**Child-friendly neighbourhood**	**Land-use mix**	**Car-friendly infrastructure**
Owning property	**.890**	−.158	.028	.068	.016
House	**.889**	−.021	.146	.070	.067
Participation in apartment design	**.853**	−.026	−.004	.104	.008
Garden	**.830**	−.028	.276	.061	−.011
Clean neighbourhood	−.161	**.845**	−.045	.012	.143
Safe neighbourhood	−.002	**.780**	−.013	.146	.137
Quiet neighbourhood	−.043	**.764**	.016	−.075	−.048
Green and low-density neighbourhood	−.019	**.538**	.298	−.035	.052
Child-friendly neighbourhood	.186	.129	**.875**	.048	−.001
Proximity to schools	.205	−.046	**.856**	.087	.025
Parks	−.070	**.523**	**.533**	.171	.126
Places of entertainment	.097	−.047	.053	**.868**	.081
Cultural/leisure facilities	.081	−.095	.176	**.846**	.081
Shopping facilities	.101	.353	−.040	**.634**	−.111
Accessibility by car	.046	.074	.053	.061	**.911**
Parking	.020	.153	.015	.007	**.899**
Eigenvalues	3.136	2.679	2.009	1.966	1.729
Percent of variance	19.60%	16.75%	12.56%	12.29%	10.81%

number of clusters. Both the statistical elbow criterion (high increase in the error sum of squares) and a consideration of the content of the clusters suggest a solution with five clusters (Backhaus et al., 2008, p. 430). Since the agglomerative approach of this method does not allow the modification of the objects once assigned to the clusters, as a second step we use the *k*-means procedure to optimise the clusters, with the number of clusters and the calculated cluster centres.

Figure 3 shows the results of the cluster analysis. Five clusters are identified which are named *child-friendly living*, *car-oriented living*, *urban living, homeowner living* and *sophisticated living.* Except for the cluster *sophisticated living*, each cluster focuses on a specific and fairly limited set of housing and neighbourhood criteria used for making their decision about relocation. Thus the residents relocated to the same neighbourhood despite different preferences in terms of housing and neighbourhood characteristics. This suggests that inner-city areas can satisfy a variety of preferences.

3.3.2 Mode use

In the following section the mobility options and the actual use of modes will be analysed. To consider the mode use of the residents in Alter Schlachthof in the broader context of urban mobility, we will first compare it to the mode use among the population in inner and outer Berlin. For this purpose we use the dataset “Mobility in Cities – SrV 2008”, which is based on mobility parameters reported for a reference day. As the second step, we analyse typical mode use for the time period of one month, differentiated between the five clusters. Information about typical mode use was gathered as follows: respondents were asked to report how often they use the car, use public transport, cycle and walk when undertaking 13 different activities including, for example, work, shopping and leisure activities. The frequencies were reported on five-point ordinal scales (never, less than once in a month, 1–3 times per month, 1–3 times per week, (almost) every day). An average number of days per month is assigned to each category – for example, the category '(almost) every day' corresponds to 22 days a month. We first calculate the sum of frequencies for all activities, categorised by mode. We then calculate individual modal shares by dividing mode-specific frequencies by the calculated sum of the frequencies of all activities.

Figure 3: Classification according to residential preferences (mean of principal components) (Data: Alter Schlachthof 2012)

4 Results

4.1 Mobility options and mode use

4.1.1 Mobility options

Table 4 shows the mobility options available to the households in Alter Schlachthof in comparison with those for the populations of inner and outer Berlin. Household car ownership in Alter Schlachthof is well above the average of households in inner and outer Berlin. In the area of terraced houses, 69% of the households indicated that they have one car, and 20% that they possess two or more cars. In the area of apartment buildings, 68% of the households own one car and 11% own two or more cars. Only 12% of the households in the area of terraced houses and 21% in the area of apartment buildings are without a private car, whereas more than half the households in the inner city have no car. Of the households in the area of terraced houses, 80% have at least one bicycle, as do 66% of the households in the apartment buildings – this latter percentage being roughly comparable to inner and outer Berlin. Furthermore, almost every other resident living in the area of apartment buildings indicated that he/she has a monthly or annual public transport season ticket, a proportion comparable to inner Berlin. In the area of terraced houses, the proportion of residents with a monthly/annual public transport season ticket stands at 42%, which in turn is comparable to outer Berlin.

Table 4: Mobility options in Alter Schlachthof and inner and outer Berlin (Data: Alter Schlachthof 2012 and "Mobility in Cities – SrV 2008", sample Berlin, Senatsverwaltung für Stadtentwicklung und Umwelt Berlin, Abteilung Verkehr)

		Alter Schlachthof		Inner Berlin	Outer Berlin
		Area of terraced houses	Area of apartment buildings		
Percentage of households with:	no car	12%	21%	56%	35%
	one car	69%	68%	40%	52%
	two or more cars	20%	11%	5%	13%
Percentage of households with at least one bicycle		80%	66%	63%	65%
Percentage of residents (>17 years) with monthly or annual season ticket for public transport		42%	49%	48%	41%
Sample size		178	138	11,093 persons/ 6,807 households	21,060 persons/ 11,433 households

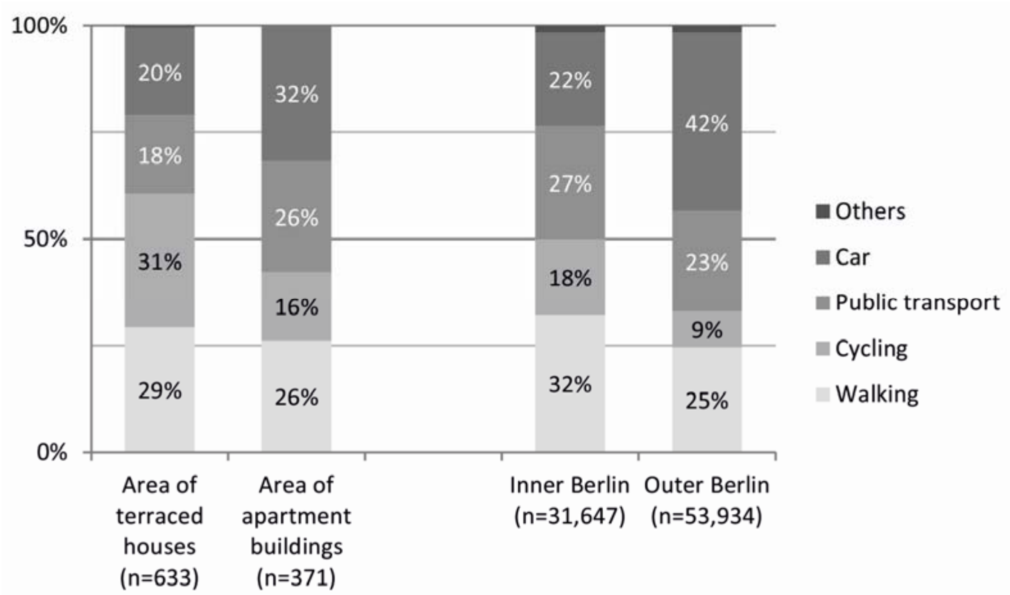
Note: Data for inner and outer Berlin is weighted.

Figures are rounded to the nearest integer

4.1.2 Mode use in Alter Schlachthof in comparison with inner and outer Berlin

Figure 4 shows the modal split of the residents living in Alter Schlachthof in comparison with the residents of inner and outer Berlin, on the reference day used in the surveys. Since only residents aged 18 years or older were asked to fill in the questionnaire in Alter Schlachthof, we control for the age distribution for the following analysis, and restrict the data for inner or outer Berlin to that for persons aged 18 years or older only.

Overall, we found statistically significant differences (chi-square test, $p<0.001$) between the car use and bike use of the residents living in the research area and the residents of Berlin (see Figure 4 for detailed significant differences). Since the residents in Alter Schlachthof are very well equipped with cars, we expect high rates of car use. However, the results reveal that high car *ownership* does not translate directly into high car *use*. Residents living in the area of terraced houses use the car for 20% of all trips, which is comparable to the population of the inner city (22%). In the area of apartment buildings, residents use the car more often (32%). Environmentally friendly transport modes are overall well represented, particularly in the area of terraced houses. More than every other trip is by means of a non-motorised transport mode. The bicycle seems to be a particularly important mode, accounting for 31% of all trips. The residents of the area of terraced houses and those living in the area of apartment buildings use public transport for 18% and 26% of all trips respectively. The latter is comparable to the rate of public transport use by the population living in inner Berlin.



Note: Data for inner and outer Berlin is weighted.
Significant differences p<0.005 (Pearson, chi-square test):
Area of terraced houses – Inner Berlin: walking, cycling, public transport
Area of terraced houses – Outer Berlin: cycling, car
Area of apartment buildings – Inner Berlin: walking, car
Area of apartment buildings – Outer Berlin: cycling, car

Figure 4: Mode use (at a reference day) of residents living in Alter Schlachthof in comparison with the population of inner and outer Berlin (residents >17 years only) (Data: Alter Schlachthof 2012 and “Mobility in Cities – SrV 2008”, sample Berlin, Senatsverwaltung für Stadtentwicklung und Umwelt Berlin, Abteilung Verkehr)

4.1.3 Mode use in Alter Schlachthof differentiated by preference clusters

Taking a closer look at the travel behaviour of the residents living in Alter Schlachthof, further differences in the modal split appear. In section 3.3.1, five resident clusters with specific preferences concerning land use and housing were identified. Although they experience the same characteristics of the built environment in their residential location, they differ with regard to mode use (see Figure 5). The clusters *child-friendly living* and *urban living* are characterised by high usage of environmentally friendly transport modes. The cluster *child-friendly living* has the highest share of non-motorised transport modes (57%) among the five clusters. The cluster *urban living* is characterised by the highest share of public transport use (42%). Consequently, the modal share of the car among these groups is very low, with 10% car use in the cluster *child-friendly living* and the same for the cluster *urban living*. The cluster *car-oriented living*, by way of contrast, displays the highest share of car use, at 37%. The clusters *homeowner living* and *sophisticated living* do not differ substantially from each other in terms of mode use.

4.2 Model results

The final model results are shown in Table 5. When developing the models, we removed statistically insignificant explanatory variables from the final versions of the models. We discuss these variables below.

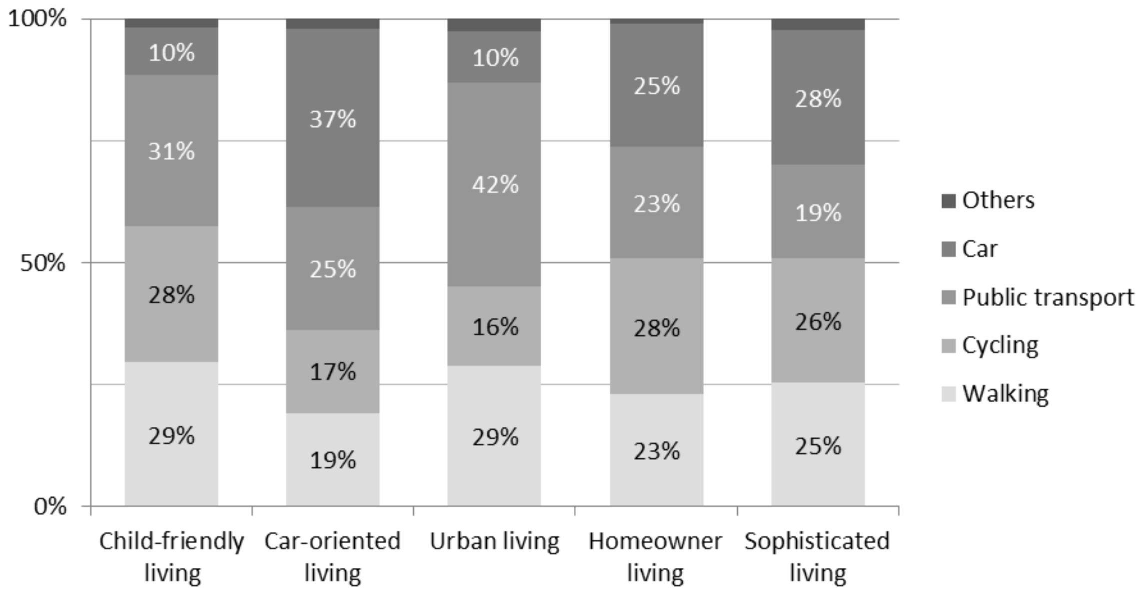


Figure 5: Typical mode use (for the time period of a month regarding different activities), for the five study clusters in Alter Schlachthof (Data: Alter Schlachthof 2012)

Table 5: Linear regression results (standardised regression coefficients) – the influence of sociodemographics, mobility options and residential preference clusters on mode use (Data: Alter Schlachthof 2012)

	Car	**Public transport**	**Cycling**	**Walking**
Sociodemographics				
Age in years				0.177**
Household type: couple (1=yes)	0.332***			
Child (<12 years) in household (1=yes)		−0.216**		0.382***
Occupation type (full-/part-time) (1=yes)				−0.251***
Mobility options				
Number of cars per household	0.520***	−0.164*	−0.400 ***	
Season ticket (monthly/annual) for public transport (1=yes)	−0.432***	1.121***	−0.804***	
Number of bicycles per person (>6 years)			0.285**	
Residential preference clusters				
Car-oriented living (reference category)	–	–	–	–
Child-friendly living (1=yes)	−0.393***	−0.032	0.280**	0.144*
Urban living (1=yes)	−0.492***	0.130	−0.045	0.245***
Homeowner living (1=yes)	−0.126	−0.103	0.266**	0.065
Sophisticated living (1=yes)	−0.121	−0.002	0.184	0.056
Adjusted R²	0.36	0.55	0.28	0.15
Sample size	236	235	236	233

Note: Fractional logit regression model
*Significance: *** = 0.01, ** = 0.05, * = 0.1*

4.2.1 Sociodemographics

The influence of sociodemographics varies across the models. For walking, sociodemographics are particularly relevant, whereas cycling is unaffected by sociodemographic variables. Overall, it is found that age, household composition and employment status all influence mode use. Being older is associated with an increased share of walking, but does not affect the use of other transport modes. Couples are more likely to travel by car than singles or families, and, if children (<12 years) live in the household, individuals tend to use public transport less often. Being employed is found to be negatively associated with walking.

The following variables were tested, but found insignificant: the quadratic function of age does not influence mode use. Gender does not affect the use of any mode, either as a main effect or in its interaction with age and household size. Income and education are not found to be significant in any of the models.

4.2.2 Mobility options

Mode use is greatly influenced by the mobility options available. The number of cars per household positively affects car use, whereas it negatively influences public transport use and cycling. As expected, if a monthly or annual season ticket for public transport is available, individuals use public transport more often and drive and cycle less often. An increasing number of bicycles per person (>6 years) tends to increase the share of cycling, but it does not affect car use, public transport or walking. The possession of a bicycle therefore appears to have a smaller impact on the overall mode choice than the possession of a car or a monthly/annual public transport season ticket.

4.2.3 Residential preferences

As expected from the descriptive analysis, the cluster *urban living* has a negative influence on car use but positively affects cycling and walking, compared to the reference cluster *car-oriented living*. The cluster *urban living* is characterised by higher shares of walking and public transport use and lower shares of car use, in comparison with the reference cluster *car-oriented living*. This underpins the descriptive analysis suggesting that the clusters *child-friendly living* and *urban living* are associated with environmentally friendly transport modes. In comparison with the reference cluster *car-oriented living*, the cluster *homeowner living* positively affects the share of cycling. Overall, the models indicate that the preference clusters significantly influence mode use.

We also estimated the regression models using preference factor scores to investigate whether they performed better than those with clusters. We found that the goodness of fit of the models explaining public transport and walking shares deteriorated when including the factor scores instead of the clusters. The model for car use as well as the model for cycling shares improved slightly with the factor scores. Overall, the models using clusters perform better than those with factor scores.

5 Conclusions

This paper has contributed to the residential self-selection (RSS) debate in travel studies by investigating mode use as a function of residential preferences, sociodemographics and mobility options. The study provides evidence that residents, although choosing to live in the same neighbourhood, have heterogeneous residential and travel preferences and, as a consequence, differ concerning their daily mode use. Thus, the findings contribute to a more nuanced understanding of the theoretical and empirical discussion about residential self-selection (RSS).

The study was conducted in an inner-city area which has a unique character: although located at the border of the inner-city districts, it combines both urban and suburban characteristics within the same neighbourhood. Most studies analyse RSS in two different sets of neighbourhoods, such as urban neighbourhoods versus suburban neighbourhoods (e.g. De Vos et al. (2012), Kamruzzaman et al. (2015), Schwanen and Mokhtarian (2004, 2005), Handy et al. (2005)). The majority of people moved into the area no more than a few years prior to the survey, meaning that self-selection has actually taken place shortly before the survey.

A comparison of residents' mode use with that of the general population of inner and outer Berlin shows that this kind of inner-city neighbourhood encourages even affluent households with high levels of car ownership to use modes other than the car. What is more, we found variety in mode use due to various reasons for self-selecting (as an outcome of residential preferences). This emphasises the impact of residential preferences on mode choice, even within a homogenous neighbourhood. Moreover, we found that individual mobility options, such as car ownership, play a significant role for mode choice. Therefore, it is important to understand the drivers of these long-term mobility decisions that influence daily mode choice. With regard to sustainable urban planning it is important to further analyse the motivation why residents living in inner-city areas with various alternative transport options feel the need to purchase or to keep a private car. Urban planning policies should therefore try to adapt new inner-city areas to the needs of future residents. Two out of the five identified clusters, for example, do not indicate a preference for car-friendly infrastructure in the neighbourhood. However, the area is fully equipped with private and public parking. This space could have been used for other purposes than parking. Whenever possible, future residents should have the opportunity to participate in adapting their own neighbourhood to their own preferences. Nevertheless, it is important to give priority to sustainable travel modes even in cases of car-oriented preferences, as even car-owning households will probably use more sustainable modes if they are well developed, and these households should not be encouraged to move to the urban fringe.

Another policy conclusion is that the high land prices in the area and the high incomes found in the sample suggest a strong demand by middle- and upper-class families for inner-city living. This has been identified as a key trend of re-urbanisation in German cities (Brake and Herfert, 2012), and it may reflect a new type of 'internal suburbanisation' within the cities' central areas (Frank, 2013). This observation also suggests the promotion of social housing for the urban poor in order to tackle the segregation of high- and low-income households.

With reference to the re-urbanisation debate, we do not find evidence that our study area attracts residents from suburban areas. Most of the residents had previously already been living in inner-city areas. However, the research suggests that specific housing characteristics that can rarely be found in dense inner-city areas, such as 'owning a house with a garden', are very important to some of the residents. This suggests that if there were no adequate supply of the right kind of dwelling in the inner city, these residents might have moved to suburban areas to satisfy their housing preferences. This emphasises the need for diverse housing types in urban areas so as to attract a variety of population groups.

From a methodological point of view, the results indicate that using clusters rather than dimensions as a more holistic way of describing residential preferences is useful for understanding mode use. Analysing residential preferences as separate dimensions does permit us to distinguish between the effects of different preferences; however, it fails to take into account the way that peoples' various residential preferences interact, forming an entirety, so to speak, on the individual level. Clustering the residents according to their residential preferences permits a study of the influence of *combinations* of preferences on travel behaviour.

A number of caveats are called for here. Firstly, this study focused on mode shares. It is possible that even individuals displaying a low *proportion* of car use actually do cover a considerable distance by car. Hence, further research should focus on vehicle-miles travelled, to draw more rigorous conclusions on sustainability in travel behaviour. Secondly, our research is based on only one inner-city area, one which was specifically designed to attract families. More case studies on both similar and different areas would allow firmer conclusions to be drawn. Thirdly, the wider criticism of methodology raised in the debate on residential self-selection and travel applies to our study as well, which has to do with the direction of causality. The most pertinent issue is probably the emergence of preferences, specifically the question of whether and how residential preferences are shaped by the built environment, rather than the other way round.

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