Residential location, travel and energy use: the case of Hangzhou Metropolitan Area

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Abstract

This paper presents the results of a study of influences of residential location on travel behavior in Hangzhou Metropolitan Area, China. The location of the dwelling relative to the center structure of Hangzhou Metropolitan Area exerts a considerable influence on the travel behavior of the respondents. On average, living close to downtown Hangzhou contributes to a lower total amount of travel, a higher share of trips by bike or on foot, and lower energy use for transport. The location of the dwelling relative to the closest second-order and third-order center also influences travel, but not to the same extent as the location of the residence relative to the city center of Hangzhou. The geographical differences in travel behavior exist independently of residential preferences and attitudes to transport and environmental issues and can therefore not be explained by residential self-selection.

1. Introduction

Previous studies in a number of European, American and Australian cities have shown that residents living close to the city center travel less than their outer-area counterparts and carry out a higher proportion of their travel by bike or by foot (cf. e.g., Mogridge, 1985; Newman & Kenworthy, 1989; Næss, Røe & Larsen, 1995; Fouchier, 1998; Stead & Marshall, 2001; Schwanen et al., 2001; Næss & Jensen, 2004; Næss, 2006; Zegras, 2009). These relationships make up an important part of the foundation for the policies of planning authorities in several European countries aiming at a more compact and concentrated urban development. However, very few studies of land use and travel have been carried out in an Asian context. Moreover, many earlier studies into this issue have been criticized for failing to control for other possible sources of influence and for not being able to establish whether a *causal* relationship exists between urban structure and travel behavior.

This paper is based on a comprehensive study of residential location and travel in an affluent Chinese urban region: the Hangzhou Metropolitan Area (Næss, 2007). The focus of the study is the transport consequences of the location of the residence within the spatial/functional urban structure.[1] Hangzhou is the capital of the Zhejiang province and is located in south-eastern China, 180 kilometers south-west of Shanghai and is the economical and political center of this province. Hangzhou Metropolitan Area includes 4 million inhabitants of which 2 million live in the continuously built-up urban area of the city of Hangzhou.

In which parts of Hangzhou Metropolitan Area will it be favorable to locate future residential development if the aim is to limit or reduce the amount of private motoring? Needless to say, such knowledge is of a high relevance to policy-making and planning, especially in a context of global warming and dwindling oil resources. Nearly one half of the World's current construction of buildings takes place in China, especially in the growing metropolitan areas along the eastern coast. In Hangzhou, 20 year old housing areas are considered old. This illustrates the rapid pace of change. Compared to cities in Europe and America, where it usually takes several decades to bring about a significant change in the urban form, the much higher pace of construction in Chinese cities implies that the increase in building stock during the next couple of decades may change the spatial structures of these cities dramatically. If Chinese cities are to follow the path that North American and many European cities have followed in their urban development and transport policies during the latest half of the 20th century, a very strong increase in urban motoring must be expected, with associated problems related to oil consumption, air pollution, health, traffic accidents, and reduced accessibility to facilities for people who do not possess a private car. It is therefore of a high policy relevance to identify possible strategies for urban development that may reduce car dependency and provide a high accessibility for the inhabitants to workplaces, service facilities and other urban functions without having to rely on a high level of individual motorized transport.

Similar to European cities, the historical urban cores of Chinese cities are usually the areas with the highest concentration of workplaces, retail stores and other service facilities. Typically, Chinese cities have a hierarchical center structure with a main center, a few sub-centers, several community centers and a number of local centers (Yuanyuan, 2004). Hangzhou Metropolitan area is no exception. The inner city of Hangzhou has an unchallenged status as the dominating center of the metropolitan area. The population density in this part of the region is considerably higher than in the outer parts of the region. There is a clear tendency to decreasing density of population as well as workplaces when the distance from the city center of Hangzhou increases. In particular, the concentration in the downtown area and its closest surroundings is strong for the office and service workplaces. Industrial workplaces are to a higher extent located in a belt in the outer eastern and northern parts of the city of Hangzhou, and in the new Economic and Technical Development zones of Binjiang (at the south side of the Qiangtang river) and Xiasha.

Hangzhou Metropolitan area also has a number of lower-order centers. The central parts of the towns of Xiaoshan and Yuhang (North-east) could be characterized as *second-order centers.* Both these towns include a comprehensive set of center functions, with a variety of workplaces as well as service facilities. The range and number of specialized functions is, however, lower than in the central part of Hangzhou. Six smaller towns and villages outside the city of Hangzhou (Yuhang (West), Liangzhu, Tangxi, Yipeng, Guali and Linpu) make up the category of *third-order centers*. These centers, too, include a more or less comprehensive set of center functions, but with a considerably more narrow range (generally limited to the less specialized types of functions) and with a lower number of facilities within each category than the higher-order centers.

2. Theoretical background and research questions

A comprehensive account of the theoretical base of the study is given in Næss (2007:31-58), see also Næss (2004, 2005 and 2006). Due to space constraints, only a few main points will be reiterated here. According to theories of transport geography and transport economy, the travel between different destinations is assumed to be influenced on the one hand by the reasons people may have for going to a place, and on the other hand by the discomfort involved when traveling to this location (Jones, 1978). By determining the distances between locations where different activities may take place, and by facilitating various modes of traveling, the urban structure makes up a set of conditions facilitating some kinds of travel behavior and discouraging other types of travel behavior. The causes of travel behavior of course also include personal characteristics of the travelers, such as age, sex, income, professional status, as well as values, norms, lifestyles and acquaintances. The emerging transportation pattern (choices of destinations, modes of traveling and trip routes) is a result of people's resources, needs and wishes, as modified by the constraints and opportunities given by the structural conditions of society.

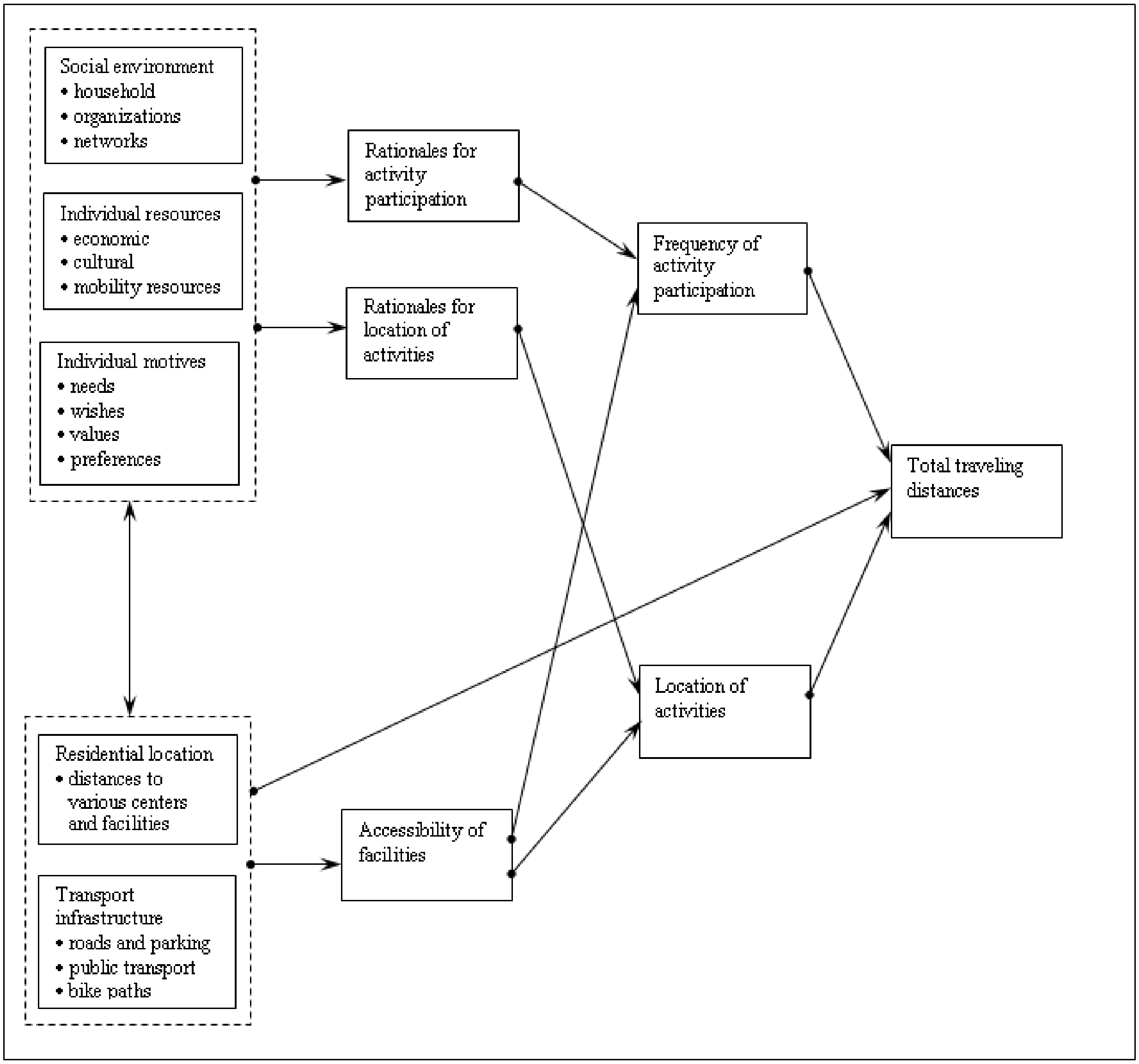
In spite of decentralizing trends, most cities – in China as well as in Western countries – still have a higher concentration of workplaces, retail, public agencies, cultural events and leisure facilities in the historical urban center and its immediate surroundings than in the peripheral parts of the urban area (among others, Newman and Kenworthy, 1999:94-95; Yuanyuan, 2004). The inner and central parts of the metropolitan area include the largest supply of work opportunities, the broadest range of commodities in the shops, as well as the highest diversity of service facilities. For residents of the inner and central parts of the city the distances to this concentration of facilities will be short. Inner-city residents could thus be expected on average to make shorter daily trips than their outer-area counterparts, with a higher proportion of destinations within acceptable walking or biking distance.

Figure 1 shows a simplified model of the ways in which individual, urban structural and other social conditions are assumed to influence daily-life traveling distances through accessibility[2] of facilities, rationales for activity participation and location of activities, frequencies of activity participation and actual location of activities[3]. The location of the residence relative to various centers and facilities, combined with the transport infrastructure on the relevant stretches, determines how accessible these centers and facilities are from the dwelling. Accessibility will be higher the lower is the *friction of distance* (Lloyd & Dicken, 1977), where the latter is a function of the time consumption, economic expenses and inconvenience involved when traveling from one place to another. Other things equal, the accessibility will of course be highest for the closest facilities. However, the ease of access varies with travel modes, depending on, among others, the layout of the public transport network, the driving conditions along the road network, the conditions for walking and biking, and individual mobility capabilities.

The residents' individual resources, motives and social environments influence their rationales for activity participation (including their tradeoff between motivation for participation and friction of distance) and location of activities (notably their balancing between proximity and the quality of facilities). Combined with the accessibility of various facilities, these rationales influence the frequency of activity participation as well as the actual locations chosen for the various activities. The total distance traveled is a consequence of the geographical locations chosen for the activities in which the resident participates, the distance along the transport infrastructure network from the residence to these locations, and the frequencies at which the various activities are carried out[4].

There are also mutual influences between the urban structural situation of the dwelling (location relative to various centers and facilities, and local transport infrastructure) and the individual and household characteristics. The possibility of an over-representation in certain geographical locations of respondents with a priori socioeconomic characteristics and attitudes predisposing them for a certain type of travel behavior (e.g. a preference for local facilities and travel by bike) necessitates multivariate control for such characteristics in order to assess the influences of urban structural variables. On the other hand, certain socioeconomic characteristics and attitudes (e.g. car ownership and transport attitudes) may themselves be influenced by the urban structural situation of the dwelling.

Figure 1 *Model showing the assumed links between urban structural, individual and social conditions, accessibility to facilities, rationales for activity participation and location of activities, actual activity participation and location of activities, and total traveling distances.*



With the above theoretical considerations as a background, the study in the Hangzhou metropolitan area has focused on the following research questions, of which the first could be characterized as the main one and the three next as secondary questions:

- Which relationships exist between the location of the residence within the urban structure and travel behavior (amount of transport and modal split), when taking into consideration demographic, socioeconomic as well as attitudinal factors?
- Does the location of the residence within the urban structure influence the range and frequency of activities in which people engage?
- On which rationales do people base their choices of activity locations and travel modes?

- Are the relationships between residential location and travel behavior different among different subgroups of the population?

3. Methods

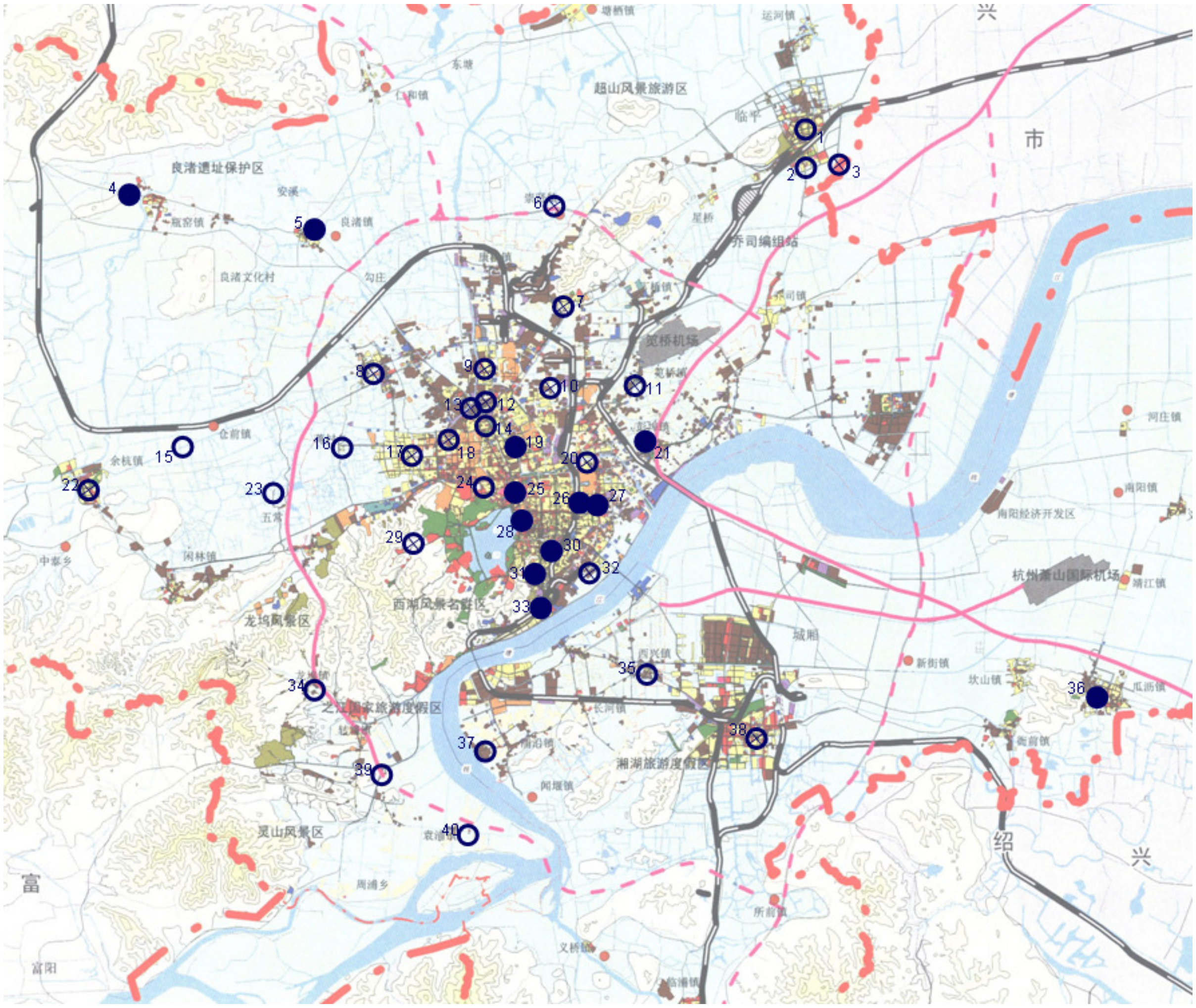
The study was carried out by means of a combination of quantitative and qualitative research methods. Besides recording urban structural conditions by means of maps, aerial photographs and visits in the investigated urban districts and residential areas, the investigation was based on 28 qualitative interviews and answers from 3154 individuals participating in a questionnaire survey conducted in June 2005. This paper concentrates on the quantitative part of the study. The respondents were recruited from residential areas varying in their urban structural situation in terms of distance to downtown Hangzhou and local centers, density, availability of local facilities etc. Questionnaires were distributed personally to residents of the selected residential areas willing to participate in the investigations.[5] 92 % of the respondents were recruited from the 40 residential areas shown in Figure 2. In addition, some 240 respondents were recruited from 75 other locations within the metropolitan area, each contributing with less than 10 respondents. The city center of Hangzhou is located at the northeastern shore of the lake, close to residential area no. 28.

Recruiting participants of our investigation from a limited number of demarcated residential areas instead of, e.g. drawing a random sample among the inhabitants of Hangzhou Metropolitan Area, was partly motivated from the possibility of mapping several urban structural properties in each area and include this range of characteristics as variables in our study. Limiting the number of locations was also necessary in order to avoid making the process of delivering and collecting questionnaires a too laborious task. Because questionnaires were only delivered to those residents of the chosen areas who were at home and accepted to participate in the investigation, it is not possible to calculate a response rate based on the numbers of distributed and collected questionnaires. However, based on information from the investigation assistants, the residents participating in the main survey made up a high proportion of the total number of dwellings where doorbells were rung. The method of selecting respondents also makes it problematic to carry out statistical generalizations from our sample of respondents to the populations of the Hangzhou Metropolitan Area. Therefore, the statistical levels of significance are only indicators of the certainty of the various relationships found within the sample. A generalization from our sample to the inhabitants of the metropolitan area must instead rely on qualitative arguments to a large extent (Sayer 1992:103): To what extent do our residential areas, seen as a whole, deviate from the residential areas of the Hangzhou Metropolitan Area in general with respect to characteristics relevant to our research questions? To what extent do relevant characteristics of the individual respondents, also seen as a whole, differ from the total population of the Hangzhou Metropolitan Area? Does it appear likely and reasonable to assume that differences between the sample and the population of Hangzhou Metropolitan Area have exerted decisive influence on the relationships found between residential location and travel behavior? (For a more thorough discussion, see, Næss, 2004:153-156.)

Table 1 shows some key characteristics of the respondents of the main survey. Female respondents are somewhat overrepresented, whereas the proportion of students/pupils appears to be quite low (yet statistics for the proportion of students among the metropolitan population are not available). Moreover, the proportion of respondents belonging to a household with at least one car is only one third of what it was among the metropolitan population two years later (2007). Given the very rapid growth in car ownership rates in Hangzhou (in 2002 the proportions of households owning a car was only one tenth of the 2007 figure), the proportion of respondents belonging to a car-owning household is probably not dramatically lower than the proportion of the metropolitan population in 2005. Apart from this, the respondents appear to be fairly representative of the metropolitan population as well as their residential areas. In addition, multivariate statistical control makes it possible to neutralize any known biases between the sample and the population of the metropolitan area. If, for example, gender is included among the independent variables in the multivariate analysis, the controlled relationship between residential location and travel will not be seriously biased by any distortion in the gender distribution of the sample.

Figure 2 *Locations in which survey respondents live. Scale 1/320.000.*

Only locations with more than 10 respondents are shown in the figure. These locations include 2913 of the 3154 respondents, i.e. 92.3% of the respondents. The remaining 242 respondents are distributed between 75 locations with numbers of respondents ranging from 1 to 9.



Legend:

- ● Location with 100 or more respondents
- ⊗ Location with 50 – 99 respondents
- ○ Location with 10 – 49 respondents

Table 1 *Demographic and socioeconomic characteristics of survey participants*

	Respondents of survey (N = 3155) Time of survey: June 2005.	Inhabitants of Ha Metropolitan Area million) 2005 data unless indicated
Proportion of men and women	58.5 % women, 41.5% men	49.3% women, 50
Average number of persons per household	2.79	2.84
Average number of children aged 0 - 6 years per household	0.134	0.169
Average number of children aged 7 - 17 years per household	0.341	0.360
Average age among respondents/interviewees	42 years	not compara
Proportion of workforce participants among respondents/interviewees	75.4%	78.9%
Proportion of students/pupils among respondents/interviewees	2.7%	n. a.
Mean household income (1000 yuan renmimbi)	45.3	53.3
Proportion with university education of 4 years or more	11.2%	n. a.
Proportion of households having at least one motor vehicle available for private transport	18.3%	n. a.
Proportion of households having at least one e-bike available for private transport	5.0%	n. a.
Proportion of households having at least one car available for private transport	6.1%	18.87% (20(

4. Typical mobility patterns in different parts of the metropolitan area

In the following, a number of graphs are presented where the respondents have been subdivided into four categories, depending on the distance belt from the city center of Hangzhou in which they live.[6] Figure 3 a - c shows how the average total daily traveling distance during the investigated week, the distance traveled by car/taxi, and the proportion of the total distance traveled by non-motorized modes vary according to the distance belt from the city center of Hangzhou wherein the respondents live. In all these figures, respondents who have not traveled at all during the relevant investigation period and respondents with extreme total traveling distances during the week have been excluded[7]. Except for travel by car/taxi, both arithmetic means and median values are shown. For travel by car/taxi, the figure only includes arithmetic means, as less than half the respondents within each distance belt has traveled by any of these modes, and the median values of travel by these modes are therefore zero in each distance belt.

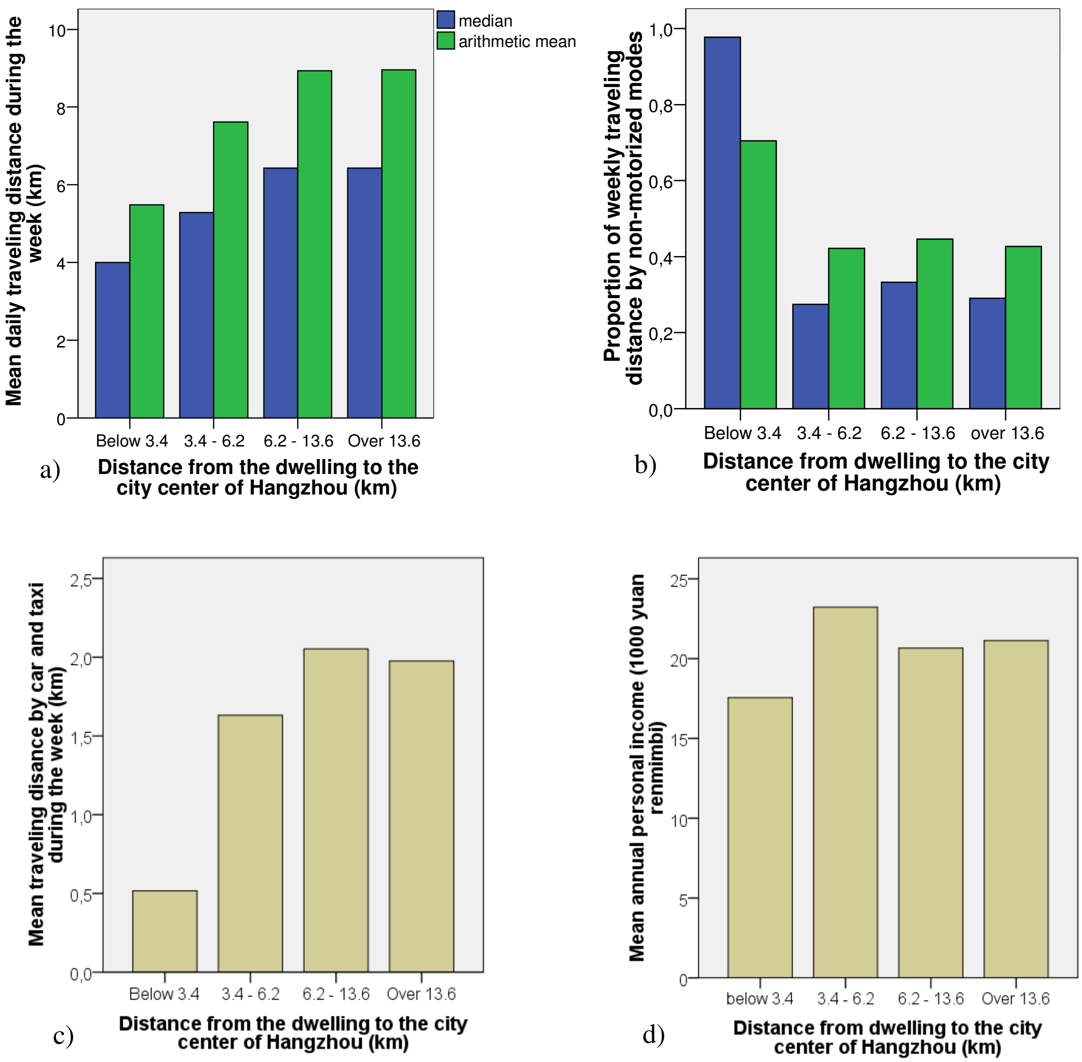


Figure 3 *Key travel characteristics and income levels among respondents (individuals) living within different distance belts from the city center of Hangzhou*
a) *Mean and median daily traveling distances during the whole week*
b) *Mean and median proportions of weekly traveling distances by non-motorized modes*
c) *Mean daily traveling distances by car and taxi during the whole week*
d) *Mean personal annual income*

N = 2829 for the three travel behavior variables, with 791, 700, 683 and 655 respondents, respectively, in the innermost, second inner, second outer and outermost distance belt. N = 2699 for personal income, with 738, 666, 665 and 630 respondents, respectively, in the four distance belts. 225 respondents with zero or extreme traveling distances (above 37.2 km daily) have been excluded from all four analyses.

We see a clear tendency to shorter traveling distances among respondents who live close to the city center of Hangzhou (Figure 3a). In particular, this applies to travel by car or taxi (Figure 3c), where respondents living less than 3.4 km from the city center of Hangzhou travel on average less than a quarter of the average distance traveled by car/taxi among the remaining respondents. Respondents living close to the city center of Hangzhou travel shorter distances than those living more peripherally also by other motorized modes (bus and e-bike). In contrast to that, the average traveling distance by non-motorized modes is about 20% longer among the respondents of the innermost distance belt than among the remaining respondents. As a result, non-motorized modes account for 70% of the traveling distance traveled among the respondents living less than 3.4 km away from the city center of Hangzhou, compared to 43% among the remaining respondents (Figure 3b). The difference between the inner and the three remaining distance belts in the proportion of non-motorized travel is larger when comparing median values than when comparing arithmetic means. This indicates that there are some respondents in all distance belts who carry out a high proportion of their travel by non-motorized modes. However, the median values show that it is much more typical among the residents of the inner distance belt than among the remaining respondents to carry out a very high proportion of the weekly travel by bike or by foot.

These differences in travel behavior do only to a limited extent reflect differences in income levels. Respondents living in the inner distance belt have on average somewhat lower income, but the income differences between these respondents and their counterparts living in the other distance belts are much smaller than the corresponding differences in travel behavior. In particular, this applies to travel by car and taxi. Moreover, whereas income levels are lower in the two outer distance belts than in the second inner belt, the respondents of the two outer belts travel longer distances in total as well as by car.

Are the differences merely a result of residential self-selection?

Several researchers within the field of land use and travel have pointed at self-selection of residents into geographical locations matching their traveling preferences as an obstacle to measuring the influences of residential location on travel. In order to throw light on the extent to which geographical differences in travel behavior are merely a result of residential self-selection, the respondents were asked to select and prioritize among three out of 20 characteristics as the most important ones if they were to move from their present residence to a new dwelling. Based on these answers, a dichotomous variable indicating whether or not the respondent showed a preference for residential locations enabling and facilitating shorter traveling distances and the use of public and/or non-motorized modes of travel was constructed. Respondents mentioning "Short distance to the workplace", "Close to shopping facilities", "Close to rail station" or "Close to bus stop" among their two highest prioritized residential characteristics were given the value 1, while the remaining respondents were given the value 0.

Figure 4 to the left shows that mean traveling distances by car are longer in the outer than in the inner parts of Hangzhou Metropolitan Area both among respondents mentioning (green color) and not mentioning (blue color), respectively, proximity to public transport, workplace and/or shopping opportunities among their three most important residential choice criteria. This suggests that travel-related residential self-selection plays a modest role, if any, as an explanation of geographical differences in travel behavior. According to Cao, Mokhtarian & Handy (2009), stronger evidence of an effect of residential location independent of residential self-selection might accrue if the travel behavior of residentially *dissonant* respondents is found to be clearly different from that of *consonant* residents in the type of neighborhood in which the former would rather live. Dissonant residents are residents living at locations poorly matching their preferences, whereas consonant residents are those who live at locations where their residential preferences are met. In our contexts, respondents prioritizing proximity to public transport, workplace and/or shopping opportunities could be considered consonant if they live in the inner distance belt and dissonant if they live in the outer three distance belts (and especially in the two outermost). Conversely, residents who do *not* consider proximity to public transport, workplace and/or shopping opportunities important could be characterized as consonant if they live in the suburbs and dissonant if they live in the inner of the four distance belt. As we can see, travel distances by car increase the further away from the city center of Hangzhou the residence is situated both among consonant ('match') and dissonant ('mismatch') residents. The difference between inner-city residents and respondents living in the outer three distance belts is particularly great among the consonant residents, as could be expected if travel behavior is (partly) influenced by transport-related residential self-selection. But there is also a clear center-periphery gradient in mean traveling distances by car among dissonant residents. Actually, respondents living less than 3.4 km from the city centre who do not emphasize proximity to public transport, workplace or shopping opportunities among their prioritized residential choice criteria travel on average considerably less by car than respondents in any of the outer distance belts who do emphasize proximity to public transport, workplace and/or shopping as important criteria for their choice of residence. If self selection was the main reason for geographical differences in the amount of travel by car, one would hardly expect to find such a pattern. In that case, we would expect to find the opposite relationship when comparing dissonant residents across the distance belts, i.e. less car travel among suburbanites who prefer proximity to transit, workplace and shopping than among inner-city dwellers who do not emphasize such characteristics of the residence. Given the fact that that the persons living in the outer belts have considerably poorer access to public transport or local services than their inner-city counterparts, this indicates a clear effect of residential location independent of residential self-selection. The possible influence of residential preferences as well as a number of other attitudinal, socioeconomic and demographic variables will be addressed more comprehensively in the next section. [8]

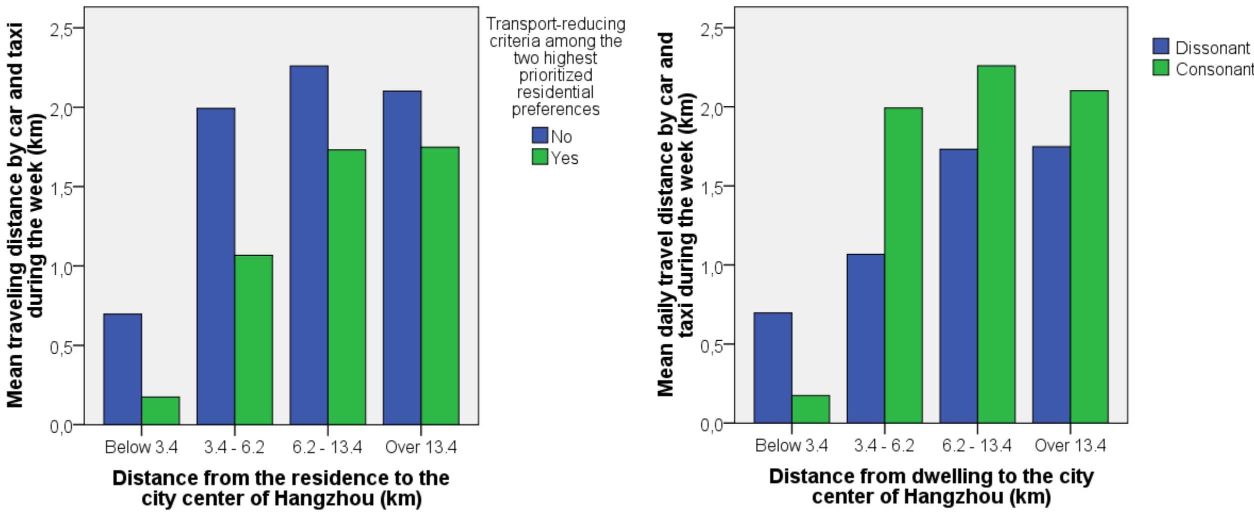


Figure 4: Traveling distances by car as a function of residential location and transport-related residential preferences.
Mean daily travel distances by car over the week among respondents mentioning and not mentioning, respectively, proximity to public transport, workplace and/or shopping opportunities among their two most important residential choice criteria (left), and among dissonant (mismatch) and consonant (match) residents (right), living in different distance intervals from the city center of Hangzhou.
N = 2829 in total (of which 1047 'yes' and 1782 'no', and 1537 'consonant' and 1292 'dissonant'), varying from 655 to 791 in the different distance intervals.

Energy use

Based on the information about the respondents' traveling distances by different modes of conveyance, their energy use for transportation during the investigated week has been calculated[9]. As can be seen in Figure 5, respondents living in the most central distance belt use on average less than half the amount of energy for transport consumed by the respondents living in the three outer distance belts. We also see that there are only small differences in energy averages between the three outer distance belts. Actually, energy use is a bit lower in the outermost distance belt than in the two middle distance belts, but still considerably higher than among the inner-city respondents. Interestingly, this tendency to reduced energy use among the most peripheral respondents is more evident when comparing median values than arithmetic means. This suggests that a relatively high proportion of the most peripherally residing respondents (e.g. farmers) work and have their other daily destinations locally within walking or biking distance, at the same time as a fairly considerable minority of the most peripheral residents travel long distances, notably to workplaces in the city of Hangzhou. On the other hand, the median energy use is zero among the respondents living less than 3.4 km from the city center of Hangzhou. This implies that more than half of the respondents of the innermost distance belt have not been traveling by any motorized mode during the entire week of investigation.

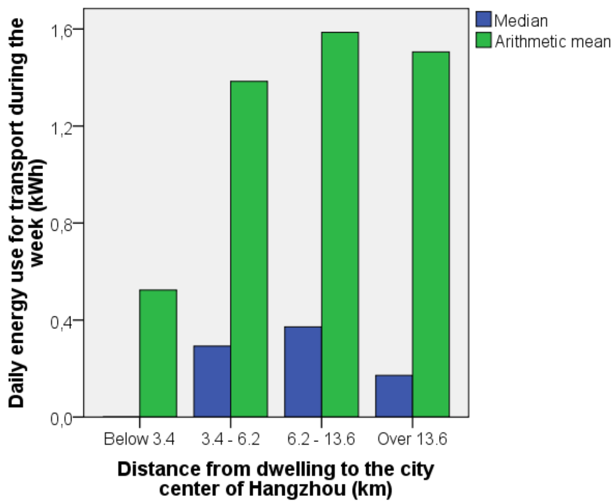


Figure 5 *Mean and median daily energy use during the investigated week among respondents living within different distance belts from the city center of Hangzhou.*
N = 2829, with 791, 700, 683, and 655 respondents, respectively, in the innermost, second inner, second outer, and outermost distance belt. 222 respondents with zero or extreme weekly traveling distances (above 262 km) have been excluded from the analysis.

6. Multivariate statistical analyses

The graphs shown in the previous section have provided some preliminary indications about relationships between the location of residences within the metropolitan urban structure and the travel behavior of the residents. However, in order to distinguish differences in travel behavior caused by residential location from differences caused by individual characteristics of the residents it is necessary to conduct a statistical control for the influence of other factors than the location of the dwelling, i.e. to "keep constant" all factors of influence apart from those, the effects of which we want to examine. In our analyses, we have included the very most of the variables mentioned in the scientific literature as potential sources of false inferences from the immediate (non-controlled) relationships between urban structure and travel. Appendix A provides an overview of the various independent variables, their assumed[10] influences on travel behavior, and (for the control variables) the reasons why we have considered it appropriate to include the variable in the analysis.

The following three urban structural variables were included in the multivariate analyses:

- The location of the dwelling relative to the city center of Hangzhou[11]
- The location of the dwelling relative to the closest second- order center.[12]
- The location of the dwelling relative to the closest third- order center (the town centers of Yuhang (West), Liangzhu, Tangxi, Yipeng, Guali or Linpu.[13]

These urban structural variables were chosen from theoretical considerations as well as iterations based on preliminary analyses of the empirical data. For all three variables, the distances measured in kilometer were transformed by means of non-linear functions. The location of the dwelling relative to the city center of Hangzhou tells something about the situation of the residence relative to the concentration of workplaces and service facilities found in the city of Hangzhou, especially in its inner and central parts. The closer to this concentration a respondent lives, the easier it will be for her/him to find a workplace matching her/his qualifications within a short distance from the dwelling, and the shorter will be the distances to special commodity shops and a number of cultural and entertainment facilities. On the other hand, if the distance to the city center of Hangzhou is too long, many residents will prefer more local job opportunities and service facilities even if these jobs and services are, apart from the traveling distances, less attractive than the central ones. The relationship between traveling distances and the distance between the residence and downtown Hangzhou is therefore not likely to be linear, but could rather be expected to follow a curve reflecting a lower propensity to use facilities in the city of Hangzhou when living in the peripheral parts of the metropolitan area.

The location of the dwelling relative to the closest second-order and third-order centers tells something about the accessibility of more local concentrations of job opportunities and services. Here, too, 'distance decay' in the form of lower propensity to use facilities in a second- or third-order center when living far away from such a center could be expected. The 'catchment areas' of the lower-order centers, i.e. the areas from which they draw a large proportion of commuters, customers, visitors to service facilities etc., are of a limited size. The distances from the dwelling to these centers could therefore be expected to influence the amount of travel within a relatively narrow zone around the lower-order centers. Beyond this zone, traveling patterns are not likely to be influenced by further increase in the distance from the dwelling to a lower-order center.

In addition to the three above-mentioned urban structural variables, the regression model included the following 18 demographic, socioeconomic, attitudinal and other non-urban-structural variables[14].

- *Demographic variables:* Sex; age; number of children younger than 7 years of age in the household; number of children aged 7–17 in the household, and number of adult persons in the household.
- *Socioeconomic variables:* Education level; personal income; car ownership; driver's license for car; whether or not the respondent is a workforce participant, and whether or not the respondent is a student.
- *Attitudinal variables:* Attitudes to transport issues; attitudes to environmental issues, and transport-related residential preferences.[15]
- *Other non-urban-structural variables* indicating particular activities, obligations or circumstances that may influence traveling distances: Whether or not the respondent had moved to her/his present dwelling less than 5 years ago; regular transport of children to/from kindergarten or school; whether or not the respondent has been outside Hangzhou Metropolitan Area during the week of investigation, and whether or not the respondent has stayed overnight away from home four or more nights during the week of investigation.

Below, we shall focus in particular on the influences of residential location on total traveling distances, the share of non-motorized travel, and energy use for transport. Main results from the remaining statistical analyses (including commuting distances and traveling distances by different modes with separate analyses for weekdays and weekends and among different population groups) are available in Næss (2007).

Total traveling distances

Table 2 shows the results of the multivariate analysis of factors potentially influencing the respondents' average daily traveling distance during the whole investigated week. According to our material, the daily traveling distance during the week as a whole is influenced by one urban structural variable: the location of the dwelling relative to the city center of Hangzhou[16]. Traveling distances tend to increase the further away from the city center of Hangzhou the dwelling is located. Controlling for demographic, socioeconomic, attitudinal and particular activities, obligations or circumstances, traveling distances are on average nearly one and a half times as long when living more than 10 km away from the city center of Hangzhou than among the respondents living closest to the city center (Figure 6, left). When the distance between the residence and downtown Hangzhou exceeds some 10 km, the effect on traveling distances from living further away from the city center of Hangzhou is still very modest.[17] This effect is in accordance with what could be expected from theoretical considerations and is also in line with findings in a number of other cities, including Copenhagen Metropolitan Area (Næss, 2005, 2006 a and b).

The influences of the variables other than residential location are in line with expectations. Traveling distances tend to increase if the household has a car at its disposal, if the respondent holds a driver's license for car, is male, has a high income, is young and/or has moved to the present dwelling during the latest five years. Hardly surprising, the traveling distance also tends to increase if the respondent has been outside Hangzhou Metropolitan Area during the week of investigation. On the other hand, having stayed overnight away from home four or more nights during the investigation period tends to contribute to reduced traveling distances.

Not surprisingly, availability of a private car in the household shows a clear influence on traveling distances. Owning a car increases people's ability to travel around and can lead to an expansion of the geographical area within which job opportunities are sought as well as more frequent and longer non-work trips. Holding a driver's license also increases the possibility of car travel and hence expands the respondents' potential radius of action. However, it should be noted that car ownership (and perhaps also possession of a driver's license for car) may itself be influenced by the location of the dwelling relative to relevant trip destinations. In order to carry out the daily program of activities within time-geographical constraints (Hägerstrand, 1970), suburbanites may consider it necessary to purchase a (second) car, whereas their inner-city counterparts, living on average closer to their daily destinations, are much less likely to feel compelled to travel by fast modes of transportation. Including car ownership among the control variables, as done in our multivariate models, therefore arguably leads to a certain underestimation of the influences of residential location on travel behavior.[18]

Table 2: *Results from a multivariate linear regression of the influence from various independent variables on the respondents' mean daily traveling distance during the investigated week (km).*
N = 2091 individuals living in different parts of Hangzhou Metropolitan Area. Adjusted R^2 = 0.189. In the table, the variables have been sorted in a descending order according to the strength of their effects (cf. the absolute values of the standardized regression coefficients). 11 variables of the original regression model failed to meet a required significance level of 0.05 and were therefore omitted in the final model..

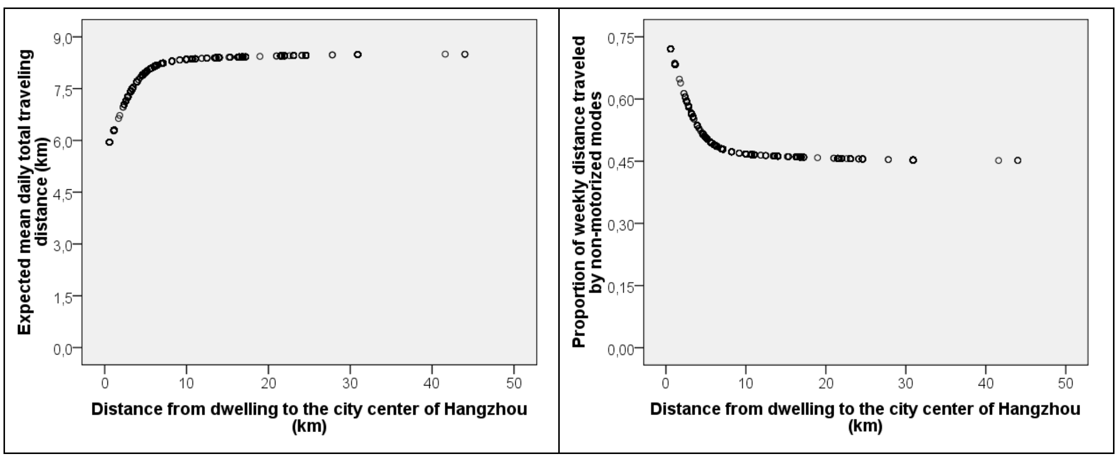
	Unstandardized coefficients		Standardi-zed coefficients	Level of significance (p values, two-tail)
	B	Std. error	Beta	
Availability of private car in the household (yes=1, no=0)	5.648	0.721	0.171	0.0000
Whether or not the respondent has been outside Hangzhou Metropolitan Area during the week of investigation (yes=1, no=0)	4.479	0.658	0.153	0.0000
Possession of driver's license for car (yes=1, no=0)	2.699	0.428	0.147	0.0000
Location of the dwelling relative to the city center of Hangzhou (non-linear distance function, values ranging from -0.23 to 1.00)	2.069	0.481	0.091	0.0000
Age	- 0.052	0.012	- 0.089	0.0000
Sex (female = 1, male = 0)	- 1.239	0.311	- 0.082	0.0001
Whether or not the respondent has stayed away from home four or more nights during the week of investigation (yes=1, no=0)	- 3.344	0.932	- 0.080	0.0003
Logarithm of personal annual income (1000 yuan renmimbi)	1.409	0.447	0.067	0.0016
Whether or not the respondent has moved to the present dwelling less than 5 years ago (yes=1, no=0)	1.154	0.394	0.059	0.0035
Attitudes to transportation issues (car-oriented = high value, values ranging from -17 to 6)	0.102	0.047	0.045	0.0309
Whether or not the respondent is a workforce participant				N. S. (p = 0.707)
Education level				N. S. (p = 0.766)
Attitudes to environmental issues				N. S. (p = 0.809)
Location of the dwelling relative to the closest third-order center				N. S. (p = 0.908)
Whether or not the respondent is a student				N. S. (p = 0.933)
Location of the dwelling relative to the closest second-order center				N. S. (p = 0.934)
Number of household members above 18 years				N. S. (p = 0.943)
Number of children younger than 7 years of age in the household				N. S. (p = 0.946)
Number of children aged 7-17 in the household				N. S. (p = 0.948)
Regular transport of children to/from kindergarten or school				N. S. (p = 0.956)
Transport-related residential preferences				N. S. (p = 0.989)
Constant	6.848	0.998		0.0000

Similar to car ownership, a high income increases people's ability to buy public transport fares, motor vehicles and fuel. The effect of income may also mirror situations where a high salary has made respondents willing to accept longer commuting distances than they would otherwise do. The effect of gender is in line with findings in several European studies and probably reflects inequalities between women and men in access to vehicles, as well as a traditionally more local job market orientation among females (see Hjorthol, 2002 and Næss, 2008 for a further discussion). The effect of having moved partly reflects situations where inner-city residents have moved to suburban dwellings located further away from their jobs, and partly a wish among recent movers to visit friends and relatives at their previous place of living.[19]

We also find a tendency to longer traveling distances among respondents with car-oriented transport attitudes, but this effect is modest (Beta = 0.045, p = 0.0309). Interestingly, none of the two other attitude variables (residential preferences and environmental attitudes) show any effect whatsoever on traveling distances (p = 0.989 and 0.809, respectively).

The effect of having stayed overnight away from home more than half of the week is more difficult to explain. Many of those who have stayed overnight away from home have been outside Hangzhou Metropolitan Area. But as the impact of having been outside the metropolitan area has already been accounted for, the effect of overnight stays away from home refers to overnight stays within the region. Possibly, some respondents stay at factory dormitories or with friends/relatives living close to the workplace during the weekdays, and their amount of travel may thus be reduced.

Figure 6: *Expected daily total traveling distance (left) and proportion of distance traveled by non-motorized modes (right) among respondents living at different distances from the city center of Hangzhou.* N = 2091, p = 0.0000 for total traveling distance; N = 2212, p = 0.0000 for share of non-motorized travel.



Non-motorized proportion of total traveling distance

Table 3 shows the results of the multivariate analysis of factors influencing the non-motorized proportion of the respondents' traveling distances during the week. When controlling for other investigated potential factors of influence, the location of the dwelling relative to the city center of Hangzhou is the variable exerting the strongest influence of all on the proportion of weekday traveling distance carried out by bike or by foot (Beta = - 0.165, p = 0.0000). The closer to the city center of Hangzhou the respondents live, the higher their proportion of walk/bike travel tends to be. As can be seen in Figure 6 to the right, the expected proportion of the traveling distance carried out by foot or by bike is as high as 72% among the respondents living closest to the city center of Hangzhou. Among respondents living more than 10 km away from the city center of Hangzhou, the expected share is around 45%, with slightly higher figures among those living around 10 km from the city center than among those living in the most remote locations. The expected proportion of walk/bike travel increases sharply when the distance from the residence to the city center of Hangzhou decreases below some 5 – 6 km.

Neither the location of the residence relative to the closest second- order or third-order center shows significant influence on the proportion of walk/bike travel.

Among the non-urban-structural variables, we find expected effects of car ownership, income, transport attitudes and possession of driver's license; where respondents belonging to a household with a car, high income, car-oriented attitudes and/or holding a driver's license tend to carry out a lower proportion of their travel on weekdays by non-motorized modes than the remaining respondents. The proportion of walk/bike travel also tends to be reduced if the respondent has a high education level, if there is more than one adult person in the household, and/or if the respondent has been outside the metropolitan area during the investigated week. The effect of belonging to a household including other adult members than the respondent may reflect the fact that it is more difficult for couples with specialized work qualifications than for single persons to adjust the locations of the workplace and residence in such a way that commuting distances are kept moderate. The two final effects (of education level and age) are a little more difficult to explain. Probably, those with a high education have a lower possibility of finding a workplace within biking distance (especially if they live in suburbs or outer parts of the metropolitan area). Older persons include pensioners who do not need to commute out of the local neighborhood, and this may explain the higher share of non-motorized travel among older people.

Table 3: *Results from a multivariate linear regression of the influence from various independent variables on the share of the respondents' traveling distance during the investigated week carried out by non-motorized modes.*
N = 2212 individuals living in different parts of Hangzhou Metropolitan Area. Adjusted $R^2 = 0.161$. In the table, the variables have been sorted in a descending order according to the strength of their effects (cf. the absolute values of the standardized regression coefficients). 12 variables of the original regression model failed to meet a required significance level of 0.05 and were therefore omitted in the final model.

	Unstandardized coefficients		Standardized coefficients	Level of significance (p values, two-tail)
	B	Std. error	Beta	
Location of the dwelling relative to the city center of Hangzhou (non-linear distance function, values ranging from -0.23 to 1.00)	- 0.204	0.028	- 0.165	0.0000
Availability of private car in the household (yes=1, no=0)	- 0.226	0.041	- 0.121	0.0000
Logarithm of personal annual income (1000 yuan renmimbi)	- 0.112	0.026	- 0.103	0.0000
Education level (professional secondary school or higher levels = 1, otherwise 0)	- 0.096	0.018	- 0.095	0.0000
Whether or not the respondent has been outside Hangzhou Metropolitan Area during the week of investigation (yes=1, no=0)	- 0.154	0.033	- 0.092	0.0000
Age	0.0032	0.0007	0.079	0.0004
Attitudes to transportation issues (car-oriented = high value, values ranging from -17 to 6)	- 0.010	0.003	- 0.073	0.0003
Number of household members above 18 years	- 0.026	0.010	- 0.047	0.0205
Possession of driver's license for car (yes=1, no=0)	- 0.068	0.024	- 0.046	0.0429
Whether or not the respondent is a workforce participant				N. S. (p = 0.707)
Whether or not the respondent has stayed away from home four or more nights during the week of investigation				N. S. (p = 0.773)
Attitudes to environmental issues				N. S. (p = 0.810)
Number of children aged 7-17 in the household				N. S. (p = 0.893)
Sex				N. S. (p = 0.910)
Location of the dwelling relative to the closest third-order center				N. S. (p = 0.923)
Location of the dwelling relative to the closest second-order center				N. S. (p = 0.937)
Whether or not the respondent is a student				N. S. (p = 0.941)
Number of children younger than 7 years of age in the household				N. S. (p = 0.941)
Whether or not the respondent has moved to the present dwelling less than 5 years ago				N. S. (p = 0.946)
Regular transport of children to/from kindergarten or school				N. S. (p = 0.955)
Transport-related residential preferences				N. S. (p = 0.990)
Constant	0.774	0.998		0.0000

Energy use for transport

A relatively high proportion of the respondents (36%) have not at all used motorized modes of transport during the week, and their energy use has accordingly been recorded as zero. This implies that the ideal requirement of ordinary least square regression analysis of normally distributed dependent variables is far from met. In order to cope with this deviation from the ideal requirements of regression analysis, we have, in line with the so-called sample selection method, carried out the analysis of energy use by different modes in two steps. First, a binary logistic regression analysis was carried out in order to identify factors influencing whether or not the respondents had at all traveled by motorized modes and hence used energy for this purpose. This analysis included the construction of a Heckman selection bias control factor (LAMBDA). This control factor was then added to an Ordinary Least Squares regression analysis of variables influencing the respondents' weekly energy use for transport. [20]. Control for selection bias was carried out according to the procedure described by Smits (2003, pp. 5-7). In both analyses, respondents who have not traveled at all during the relevant investigation period have been omitted. In the analysis of variables influencing the amount of energy used for transport, respondents with extreme total traveling distances during the week (cf. note 8) have also been excluded.

Table 4 shows the results of the multivariate logistic regression analysis of factors potentially influencing the likelihood of having used energy for motorized travel during the investigated week.

Table 4 Results from a binary logistic regression analysis of the influence variables potentially influencing the likelihood of having used energy for motorized travel during the investigated week (the selection model).

N = 2315 respondents living in different parts of Hangzhou Metropolitan Area. Nagelkercke's $R^2 = 0.204$. In the table, the variables have been sorted in a descending order according to the strength and certainty of their effects (cf. the Wald figures). 12 variables of the original regression model failed to meet a required significance level of 0.05 and were therefore omitted in the final model.

	B	Std. error	Wald	Level of significance (p value)
Location of the dwelling relative to the city center of Hangzhou (non-linear distance function, values ranging from -0.23 to 1.00)	1.211	0.151	64.70	0.0000
Education level (professional secondary school or higher levels = 1, otherwise 0)	0.628	0.102	38.21	0.0000
Logarithm of personal annual income (1000 yuan renmimbi)	0.803	0.146	30.11	0.0000
Availability of private car in the household (yes=1, no=0)	1.222	0.386	10.02	0.0016
Whether or not the respondent has moved to the present dwelling less than 5 years ago (yes=1, no=0)	0.405	0.141	8.23	0.0041
Possession of driver's license for car (yes=1, no=0)	0.411	0.146	7.90	0.0050
Overnight stay away from home four or more nights during the week of investigation (yes=1, no=0)	0.860	0.335	6.60	0.0102
Attitudes to transportation issues (car-oriented = high value, values ranging from -17 to 6)	0.040	0.016	6.54	0.0105
Age				N. S. (p = 0.071)
Attitudes to environmental issues				N. S. (p = 0.153)
Whether or not the respondent is a student				N. S. (p = 0.297)
Location of the dwelling relative to the closest second-order center				N. S. (p = 0.301)
Number of household members above 18 years of age				N. S. (p = 0.358)
Transport-related residential preferences				N. S. (p = 0.482)
Number of children aged 7 – 17 in the household				N. S. (p = 0.563)
Whether or not the respondent is a workforce participant				N. S. (p = 0.575)
Location of the dwelling relative to the closest third-order center				N. S. (p = 0.669)
Number of preschool children (less than 7 years) in the household				N. S. (p = 0.814)
Regular transport of children to/from kindergarten or school				N. S. (p = 0.965)
Overnight stay away from home four or more nights during the week of investigation				N. S. (p = 0.974)
Constant	-1.390	0.216	41.61	0.0000

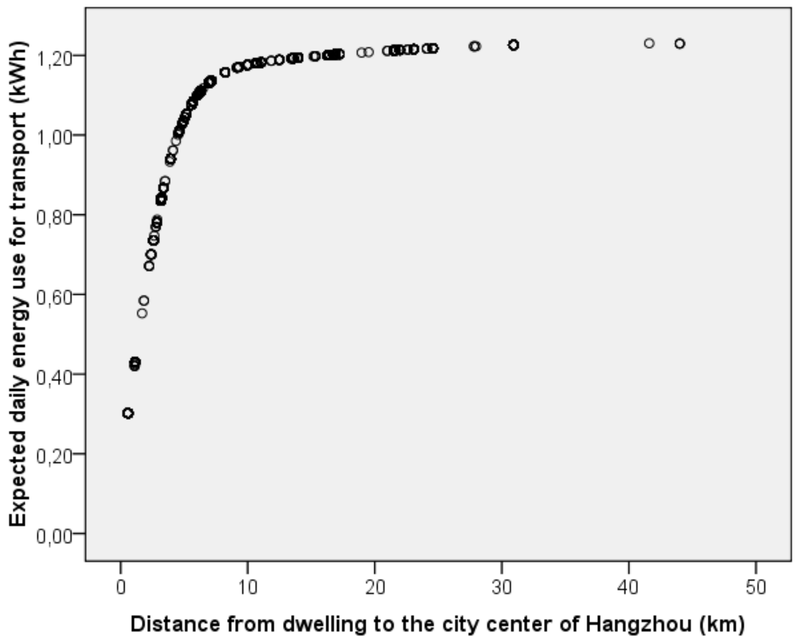
Table 5 shows the results of the multiple ordinary linear regression analysis of factors potentially influencing the amount of energy use.

Table 5: *Results from a multiple linear regression (the substantial analysis) of the influence from various independent variables on the respondents' mean daily energy use for transport (kWh).* N = 2156 individuals living in different parts of Hangzhou Metropolitan Area. Adjusted R^2 = 0.395. In the table, the variables have been sorted in a descending order according to the strength of their effects (cf. the absolute values of the standardized regression coefficients). 13 variables of the original regression model failed to meet a required significance level of 0.05 and were therefore omitted in the final model.

	Unstandardized coefficients		Standardized coefficients	Level of significance (p values, two-tail)
	B	Std. error	Beta	
Availability of private car in the household (yes=1, no=0)	4.455	0.286	0.348	0.0000
Possession of driver's license for car (yes=1, no=0)	1.434	0.137	0.202	0.0000
LAMBDA	0.609	0.128	0.109	0.0000
Logarithm of personal annual income (1000 yuan renmimbi)	0.642	0.061	0.105	0.0000
Location of the dwelling relative to the city center of Hangzhou (non-linear distance function, values ranging from -0.23 to 1.00)	0.968	0.178	0.098	0.0000
Whether or not the respondent has been outside Hangzhou Metropolitan Area during the week of investigation (yes=1, no=0)	1.026	0.194	0.091	0.0000
Attitudes to transportation issues (car-oriented = high value, values ranging from -17 to 6)	0.070	0.016	0.079	0.0000
Whether or not the respondent has moved to the present dwelling less than 5 years ago (yes=1, no=0)	0.394	0.130	0.052	0.0024
Location of the dwelling relative to the closest third-order center (non-linear distance function, values ranging from -0.93 to 1.00)	0.267	0.103	0.045	0.0096
Overnight stay away from home four or more nights during the week of investigation				N. S. (p = 0.711)
Attitudes to environmental issues				N. S. (p = 0.807)
Whether or not the respondent is a workforce participant				N. S. (p = 0.848)
Education level				N. S. (p = 0.854)
Age				N. S. (p = 0.869)
Location of the dwelling relative to the closest second-order center				N. S. (p = 0.907)
Sex				N. S. (p = 0.948)
Regular transport of children to/from kindergarten or school				N. S. (p = 0.967)
Whether or not the respondent is a student				N. S. (p = 0.973)
Number of children aged 7-17 in the household				N. S. (p = 0.976)
Number of children younger than 7 years of age in the household				N. S. (p = 0.984)
Number of household members above 18 years				N. S. (p = 0.988)
Transport-related residential preferences				N. S. (p = 0.992)
Constant	-1.245	0.305		0.0000

Based on the results shown in Table 5, predicted energy use depending of the distance from the dwelling to the city center of Hangzhou has been calculated. The results of this calculation can be seen in Figure 7.

Figure 7: *Expected daily energy use for transport among respondents living at different distances from the city center of Hangzhou.*
N = 2156.



According to our data, respondents living more than 10 km away from the city center of Hangzhou could be expected to use about four times the amount of energy for transport within the metropolitan area as the respondents living closest to the downtown area. First and foremost, this reflects a considerably higher propensity of inner-city dwellers of carrying out all their transport during the week by non-motorized modes (cf. Table 4). To some extent, those who have traveled by motorized modes also tend to use somewhat more energy the further away from downtown Hangzhou they live, but this effect is much more modest. A separate analysis among the users of motorized modes (not shown here) reveals weak tendencies of increasing energy use the further away the respondents live from the closest second-order and third-order center. However, none of the latter urban structural variables show any effect on the propensity of being a user of energy for motorized travel. Seen together, the location of the residence relative to the city center of Hangzhou therefore exerts a much stronger influence on energy use for transport than the location relative to lower-order center categories.

Among the non-urban structural variables, energy use appears to be influenced in particular by availability of private car in the household, income, and possession of a driver's license. We also find effects of whether or not the respondent has been outside Hangzhou Metropolitan Area during the week of investigation, transport attitudes, and whether or not the respondent has moved to the present dwelling during the latest five years. Energy use for transport tends to increase if the household has a car at its disposal, if the respondent holds a driver's license, if the respondent's income level is high if the respondent has been outside the metropolitan area during the week, if the respondent has car-oriented transport attitudes and/or if she/he has moved to the present dwelling during the latest five years. Neither of these effects is surprising, cf. the discussions in connection with Tables 1 and 2. The Lambda factor reflects the effect of all the unmeasured characteristics which are related to the residential choice/transport decision. The coefficient of this factor therefore catches the part of the effect of these characteristics which is related to energy use for transport (Smits, 2003, p. 3).

7. Concluding remarks

The results of the Hangzhou Metropolitan Area study are well in accordance with the conclusions from studies in Paris (Mogridge 1985; Fouchier 1998), London (Mogridge, ibid.), New York and Melbourne (Newman & Kenworthy 1989), San Francisco (Schipper et al. 1994), Oslo (Næss, Røe & Larsen, 1995), Dutch urban regions (Schwanen et al., 2001), English cities (Stead & Marshall, 2001), Danish provincial cities (Hartoft-Nielsen, 2001; Nielsen, 2002; Næss & Jensen, 2004), Copenhagen Metropolitan Area (Næss, 2005, 2006 a and b) and Santiago de Chile (Zegras, 2009). The results thus seem to be of a high generality, indicating that the dominating mechanisms by which residential location influences urban travel will be present across city sizes and considerable contextual differences.

Admittedly, some previous studies have concluded that only weak relationships or no relationship at all exist between urban structural characteristics and the inhabitants' travel behavior (see, e.g., Williams, Burton & Jenks (2000), where some of these studies are referred). However, the empirical studies concluding that urban structure has no influence worth mentioning on travel behavior have usually investigated other aspects of travel (e.g. trip frequencies or travel time) and/or focused on other urban structural conditions (e.g. detailed neighborhood design) than those which, according to our investigations, exert the strongest influences on traveling distances and modal split. Moreover, a common feature of many of the publications from the above-mentioned studies is an absence of theoretical discussion of the reasons why urban structure could be expected to influence travel, which characteristics of the urban structure could be expected to exert the strongest influence on travel behavior, and which aspects of travel behavior could be expected to be influenced by urban structure. Among theoretically informed, empirical, multivariate investigations into the influences on travel from the location of residences within the urban area, the converging conclusion is that living close to the city center does contribute to reduce traveling distances and the use of cars.

Notably, the Hangzhou Metropolitan Area study shows clear effects of residential location on traveling distances, modal split and energy use also when controlling for transport attitudes, environmental attitudes and transport-related residential preferences. The differences in travel behavior between suburbanites and inner-city residents thus cannot be explained by self-selection of residents into neighborhoods matching their travel preferences.

The results of the Hangzhou Metropolitan Area study show that it is crucial to avoid urban sprawl if China is to avoid an uncontrolled increase in motorized daily-life travel. In general, accommodating growth in the building stock by means of densification instead of outward expansion is preferable from a transport energy point of view. In particular, densification close to the main center of the urban region contributes to reduce the amount of travel and to increase the proportion of non-motorized travel. To some extent, densification close to the centers of second- or third-order towns may also be favorable. However, our analyses show that the gains in terms of access to services and workplaces locally is countered by a higher tendency among respondents living close to lower-order centers to make long commutes to workplaces in the inner areas of Hangzhou[21]. Possibly, this reflects a tendency among mobile, educated people working in Hangzhou to settle in third-order centers, thus being able to live in a more rural setting and perhaps in a single-family house while still enjoying proximity to local services.

Compared to the level of affluence among the inhabitants, the present urban form of Hangzhou Metropolitan Area may be considered largely favorable from a perspective of environmentally sustainable transport. Admittedly, some of the recent developmental areas (notably so-called economic and technological developmental zones) have a location and density not very favorable, seen from the perspective of transport energy minimizing. However, Hangzhou is still on average a dense city, and most of the outward urban expansion that has taken place in Hangzhou and in the second-order towns has been at fairly high densities, very different from the one-storey single-family home development so typical for urban expansion e.g. in many American cities.

The challenge for Hangzhou Metropolitan Area (and other similar Chinese urban areas) is maybe not to make the built-up areas even denser than they are already (although such density increases may also be relevant, in particular in the most central parts), bur first and foremost to avoid adopting the low-density, sprawling form of development typical for American, and in a more moderate form also European, urban regions during the second half of the 20th century.

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Appendix A: The independent variables included in the multivariate analyses

Independent variable	**Pre-assumed effects on travel behavior**	**Arguments for including the variable in the analysis**
Location of the residence relative to downtown Hangzhou (non-linear transformation of the distance along the road network)	Longer travel distances in total, by car and by public transport, and shorter by non-motorized modes among outer-area residents. Higher proportion traveled by car and lower proportion by walk/bike. Yet reduced effects at long distances from downtown, and maybe somewhat lower amount of travel in the very most peripheral areas	Urban structural variable of primary interest in this investigation. Not a control variable
Logarithm of the distance from the residence to the closest second-order urban center	Longer travel distances in total, by car and by public transport, and shorter by non-motorized modes among those living far from a second-order center. Higher proportion traveled by car and lower proportion by walk/bike.	Urban structural variable of primary interest in this investigation. Not a control variable
Logarithm of the distance from the residence to the closest third-order urban center	Longer travel distances in total and by car, and shorter by public transport among those living far from third-order center. Higher proportion traveled by car. Maybe also more travel by non-motorized modes (in order to reach the local service facilities located close to it)	Urban structural variable of primary interest in this investigation. Not a control variable
Sex (female = 1, male = 0)	Shorter travel distances in total and by car among women than among men. Higher proportions of public transport and walk/bike	The proportions of men and women among respondents varies somewhat between the areas. Besides, enables comparison of urban structural and demographic variables, and across population groups
Age	Shorter travel distances in total and by car, and lower proportion of car travel among old people	Age distribution varies between the residential areas, among others with a higher proportion of young people in the inner city. Besides, enables comparison of urban structural and demographic variables
Number of household members below 7 years of age	Shorter travel distances in total and by public transport, a higher proportion traveled by car and a lower proportion by public transport if there are small children in the household. Ambiguous expectations regarding travel by walk/bike	Number of children varies between the areas, among others with fewer children in the inner city and large local variations in outer areas. Besides, enables comparison of urban structural and demographic variables, and across population groups
Number of household members aged 7 - 17	Shorter travel distances by public transport, a higher proportion traveled by car and a lower proportion by public transport if there are schoolchildren in the household. Maybe also a lower proportion of walk/bike. Ambiguous expectations regarding the total travel distance	Same as for the previous variable

Workforce participation (yes = 1, no = 0)	Longer travel distances in total, by car and by public transport among workforce participants. Ambiguous expectations regarding the modal split and the distance traveled by walk/bike	The proportion of workforce participants varies between the areas. Besides, enables comparison of urban structural and demographic variables, and across population groups
Student/pupil (yes = 1, no = 0)	Shorter travel distances by car and longer by public transport and walk/bike among students/pupils, with corresponding effects on the modal split. Ambiguous expectations regarding the total travel distance	The proportion of students/pupils varies between the areas, with considerably higher shares in the inner city. Besides, enables comparison of urban structural and demographic variables, and across population groups
Pensioner (yes = 1, no = 0)	Somewhat shorter total travel distance. Ambiguous expectations regarding the modal split and the distances traveled by the various modes	The proportion of pensioners varies between the areas. Besides, enables comparison of urban structural and demographic variables, and across population groups
Personal annual income (1000 yuan renmimbi)	Longer travel distances in total and by car, and a higher proportion traveled by car, when income is high. Lower *proportions* of public and non-motorized transport.	Income levels vary considerably between the areas. Besides, enables comparison of urban structural and demographic variables, and across population groups
Whether the respondent holds a driver's license for car (yes = 1, no = 0)	Longer travel distances in total and by car, and a higher proportion traveled by car among those who wold a driver' license. Shorter distance traveled by public transport and a lower proportion of this mode. Maybe somewhat more walk/bike travel, as these modes, alike with the car, are individual and provide some of the same flexibility	The proportion holding a driver's license varies between the areas. Arguably though, the part of this variation which is not due to factors already included as variables in the analysis may to a high extent be a result of urban structural conditions, and should therefore perhaps not be controlled for.
Availability of a private car in the household	Longer travel distances in total and by car, and a higher proportion traveled by car if one or more cars is available in the household. Shorter distance traveled by public transport and walk/bike, and lower proportions of these modes.	Car ownership varies between the areas. Arguably though, the part of this variation which is not due to factors already included as variables in the analysis may to some extent be a result of urban structural conditions, and should therefore perhaps not be controlled for.
Education level (professional secondary school or higher levels = 1, otherwise 0)	Longer travel distances in total, by car and by public transport among those with a long technical or economic education, maybe also a lower proportion of walk/bike	The dominating levels and types of education varies between the areas. Besides, enables comparison of urban structural and demographic variables, and across population groups
Index for attitudes to transport issues (high value = car-oriented attitudes)	Longer travel distances in total and by car, and shorter by public transport and walk/bike among those with car-oriented attitudes. Also a higher proportion of car travel and lower proportions of public transport and non-motorized modes.	Transport attitudes vary between the areas, and this may imply self-selection of residents into neighborhoods matching their travel preferences. Arguably though, the part of this variation which is not due to factors already included as variables in the analysis may to a high extent be a result of urban structural conditions, and should therefore perhaps not be controlled for.

Index for attitudes to environmental issues (high value = environmentally oriented attitudes)	Shorter travel distances in total and by car, and longer by non-motorized modes among those with environmentally oriented attitudes. Also a lower proportion of car travel and a higher proportion of walk/bike	Same as for the previous variable
Residential preferences (mentioning proximity to public transport, workplace and/or shopping opportunities important residential choice criteria = 1, otherwise 0)	Shorter travel distances and less car driving among respondents emphasizing proximity to daily destinations and public transport stops as important residential choice criteria.	Residential preferences may vary between the areas, and this may imply self-selection of residents into neighborhoods matching their travel preferences.
Regular transport of children to school or kindergarten (yes = 1, no = 0)	Longer travel distance by car, a higher proportion traveled by car and a lower proportion by public transport among those who bring children regularly. Maybe also somewhat longer total travel distance. Ambiguous expectations regarding the distance by walk/bike and the proportion of such travel	The proportions with such responsibilities vary between the areas, maybe in a way different from the variation in the number of children in the households.
Overnight stays away from home more than three nights during the investigated week (yes = 1, no = 0)	Longer travel distances in total, by car and by public transport, and a lower proportion of walk/bike among those who have many overnight stays away from home	A sort of "noise" which it might be desirable to eliminate in the estimation of the effects of the other variables.
Official trips during the investigated week (yes = 1, no = 0)	Longer travel distances in total, by car and by public transport, and a lower proportion of walk/bike among those who have carried out official trips	A sort of "noise" which it might be desirable to eliminate in the estimation of the effects of the other variables.
Has moved to the present dwelling less than five years ago (yes = 1, no = 0)	Longer total travel distance for all modes (in particular in weekends) among those who have moved. Also more travel by car and public transport, and less by non-motorized modes	The proportion who has moved is likely to vary between the areas (some areas are more characterized by turnover than other areas)

Notes

[1] In this context, the spatial/functional urban structure applies to the geographical distribution and fabric of the building stock, the mutual location of different functions (residences, workplaces, public institutions and service) within the building stock, the transport system (road network, public transport provision, and parking conditions), and the urban green and blue structures (more or less natural areas within and close to the city, and lakes, rivers and creeks)

[2] Here, accessibility refers to the ease by which a given location can be reached, depending on its proximity, the transport infrastructure leading to it, and the visitors' individual mobility resources.

[3] The figure does not show conditions influencing the travel modes used, which make up another important aspect of the study. Travel modes could be expected to be influenced indirectly by the factors shown in Figure 2 through their influence on traveling distances, and directly by individual resources and motives, transport infrastructure and social environments.

[4] This presupposes that the residents choose more or less the shortest routes. Our qualitative material clearly indicates that this is the case for daily-life travel (Næss, 2007:144-149; see also Næss, 2005:213-214).

[5] In each area, respondents were recruited by ringing doorbells, starting from a randomly chosen building within the demarcated area. Investigation assistants (master students and Ph. D. students from Zhejiang University) explained the purpose of the study and the content of the questionnaire, enquiring one of the household members (the person above 15 years next to have her/his birthday) to answer the questions. Thus, all respondents were single individuals, and there was only one respondent from each household. The investigation assistants also collected the completed questionnaires. This procedure went on until the number of collected questionnaires in each area was considered sufficiently high or no more willing participants could be found. At the outset, we intended to recruit 100 respondents from each of 30 residential areas selected according to the criteria mentioned above. However, in some of the selected areas, less than 100 persons could be recruited. Additional respondents were therefore selected from a number of other locations. After having received the questionnaires, a quality inspection of the received material was conducted and invalid questionnaires were eliminated. As compensation, even some more respondents were recruited. These latter respondents were selected among acquaintances of the investigation team.

[6] The four distance belts have been defined in such a way that each belt includes approximately one fourth (a quartile) of the total number of respondents.

[7] By extreme traveling distances we mean traveling distances more than three interquartile ranges above the upper quartile (cf. Norusis, 1990). 181 respondents with weekly traveling distances above 261 km were excluded according to this criterion, in addition to 41 respondents who had not traveled at all during the investigated week. The respondents with extremely long traveling distances have on average higher education level, income level, car ownership and are more frequent driver's license holders than the remaining respondents, and a clear majority among them are men. They also live on average further away from the city center of Hangzhou (12.4 km) than the other respondents (9.0 km among those who have traveled non-extreme distances). On the other hand, respondents who have not traveled at all during the week also live further away from the city center of Hangzhou (12.5 km) than the average. These respondents do not differ much from the remaining respondents in terms of socioeconomic characteristics. Needless to say, all the respondents with extreme traveling distances have used energy for their transport during the week. Their level of energy use is, however, not related to any of the residential location variables and is also only weakly related to some few socioeconomic variables. This reflects the high degree of randomness regarding the destinations and distances of the trips carried out by the respondents with extreme traveling distances during the week. To a high extent the extreme traveling distances represent trips to places outside the metropolitan area, e.g. occupational trips to meetings and other business activities in other cities. The fact that the respondents with extreme traveling distances do not show any countervailing tendency to the tendency found among those respondents with non-extreme traveling distances suggests that the exclusion of the former respondents from the analysis is hardly a source of biased results. The same applies to the zero-travelers, who make up only 1.3 % of the respondents and whose energy use is zero regardless of residential location.

[8] For a comprehensive analysis of the extent to which residential self-selection represents a source of error in land use-travel issues, see Næss (2009) and other articles in a forthcoming issue of the journal *Transport Reviews.*

[9] Here, only energy use for motorized travel has been included. The additional consumption of food and beverages required to compensate for the respondents' physical activity in connection with their trips by foot and by bike was considered negligible in this context. According to the Committee on the Future of Personal Transport Vehicles in China *et al*. (2003:247–248), cars in Shanghai go 10.5 km per liter of fuel (of which 14/15 is gasoline and 1/15 is CNG/LPG), with an average occupancy of 2.5 persons. Given an energy content per liter of gasoline of approx. 9.6 kWh, average energy use per passenger km by car under Shanghai 2000 conditions is thus 9.6/(10.7*2.5) kWh = 0.359 kWh/passenger km. According to the same source, occupancy figures as well

as energy use per vehicle km are likely to remain fairly constant during the period 2000 – 2020. Wu (2008) operates with a higher energy use per passenger km by car (600 kcal, corresponding to 0.698 kWh/passenger km). The latter source is a power point presentation, but I consider it to be reliable because the author is a renowned professor of Tsinghua University. Unfortunately, the research on which Wu's power point presentation was based seems to be available only in Chinese. In my calculations, I have chosen to use the average of the figures from the two above-mentioned sources, i.e. 0.528 kWh per passenger km by car. I have used the same figure for taxi travel. According to Wu (2008), average energy use per passenger km by bus in Chinese cities is 172 kcal and by train 49 kcal, corresponding to 0.200 kWh/passenger km by bus and 0.057 kWh/passenger km by train. I have used these figures as a basis for my calculations of energy use for public transport. Data on the energy use per kilometer traveled by electronic bike were obtained from Weinert, Ma & Yang (2006). According to this source, average energy use per passenger km by e-bike is 0.014 kWh. Compared to a European context, my Chinese energy data imply lower energy use per passenger km, especially by train but also by bus and to some extent by car too. For comparison, figures from Copenhagen Metropolitan Area show 0.64 kWh/passenger km by car, 0.32 kWh/passenger km by bus, and 0.19 kWh/passenger km by train, Higher degrees of capacity utilization (more crowded buses and trains in China) is probably the main explanation of these differences.

[10] From theoretical or common-sense considerations, supplemented with information from the qualitative interviews.

[11] Based on theoretical considerations as well as preliminary, iterative analyses of the empirical data, the location of the residence relative to the city center of Hangzhou was measured by means of a variable constructed by transforming the linear distance by means of a non-linear function. This function was composed of a hyperbolic tangential function and a quadratic function, calculated from the following equation: mainhypnew = ((EXP(kmtomain*0.3 - 0.3)) - EXP(-(kmtomain*0.3 - 0.3))) / (EXP(kmtomain*0.3 - 0.3) + EXP(-(kmtomain*0.3 - 0.3))) - (0.00007*(kmtomain - 40)*(kmtomain - 40)), where Mainhypnew = the transformed distance from the dwelling to the city center of Hangzhou and kmtomain = the linear distance, measured in kilometer. The linear distance was normally measured as the crow flies, yet avoiding to cross lakes or continuous natural areas with no roads. Given a positive relationship between the transformed function and the traveling distance, this function describes a situation where traveling distances increase quite rapidly as the distance from the dwelling to the city center increases from zero up to some 6 km, then less steeply until a level where traveling distances increase only very slightly as the distance from the residence to the city center increases beyond some 10 km.

[12] Similar to the location of the dwelling relative to the city center of Hangzhou, the linear distance from the dwelling to the closest second-order center was transformed by means of a non-linear function; in this case a hyperbolic tangential function. For details, see Næss (2007).

[13] Similar to the location of the dwelling relative to the closest second-order center, the linear distance from the dwelling to the closest third-order center was transformed by means of a hyperbolic tangential function. For details, see Næss (2007).

[14] The 21 independent variables included in the multivariate analyses might appear to be a quite high number, possibly leading to so-called multicollinearity problems (unreliable statistical analyses because of too strong mutual correlations between some of the independent variables). However, formal collinearity diagnostics do not indicate any such problems. With all 21 independent variables included in the regression model, the three residential location variables have the following Tolerance levels: Location of the residence relative to downtown Hangzhou 0.76; Location of the residence relative to the closest second-order center 0.89; and Location of the residence relative to the closest third-order center 0.91. None of the 21 independent variables have Tolerance levels below 0.53. According to Lewis-Beck (1980:60) problems of high multicollinearity exist if any of the variables of the regression model has a Tolerance level "close to zero". Given the fact that the theoretical range of Tolerance levels is from 0 to 1, the Tolerance levels of the urban structural variables as well as the non-urban structural variables must be considered clearly satisfactory.

[15] Indices for attitudes to transport issues and to environmental issues were each based on seven separate questions. The respondents were asked to indicate the extent to which they agreed or disagreed to the statements about transport or environmental issues presented in each question, ticking for the relevant alternative on a 5-level Likert scale. The answer alternatives were: Strongly agree; Agree to some extent; Indifferent; Disagree to some extent; Strongly disagree. Some of the statements regarding transport issues expressed a positive and some a negative attitude to car travel. Similarly, some of the statements about environmental issues expressed a positive and some a negative attitude to prioritizing the environment over other concerns. Values of the separate variables from which the indices were calculated were coded in such a way that high index values indicated, respectively, car-oriented transport attitudes and a strong concern for environmental protection. The residential preference variable is the same one as described in the paragraph on self-selection in section 4.

[16] Here, traveling distances have been measured as the actual distances traveled. Respondents with extreme mean travel distances (above 37.2 km daily) have been excluded. In addition, a number of respondents have failed to provide information about traveling distances and/or to answer other questions of the questionnaires. The number of respondents on which the tables 2 – 5 and figures 6 -7 are based is therefore lower than the number of respondents whose travel distances meet the above-mentioned criteria. In spite of the exclusion of respondents with extreme values, the distribution of traveling distances deviates somewhat from normality (mean 7.70, median 5.29, skewness 1.684 and kurtosis 2.705). If instead logarithmically transformed traveling distances are used in the analysis, the distribution is closer to normality (mean 0.694, median 0.724, skewness -0.671 and kurtosis 0.802). Including the same independent variables in the model, the effect of residential location relative to downtown Hangzhou increases (Beta = 0.153, p = 0.0000), and we also find an effect of the location relative to the closest second-order center (Beta = - 0.055, p = 0.0070). The latter effect is negative, indicating that respondents living close to a third order center travel, other things equal, somewhat longer than their counterparts living in more rural areas at the same distance from downtown Hangzhou.

[17] As mentioned in Note 14, the transformation of the simple distance to downtown into a non-linear distance function was based on an iterative process where different functions (including cubic, quadratic, hyperbolic-tangential, and a combination of the two latter) were tried out, as well as different parameter values of each of these functions. The chosen transformation was the one showing the highest goodness of fit. A model where the chosen transformation was replaced with the simple linear distance to downtown showed a considerably lower goodness of fit.

[18] For a further discussion, see Næss (2006), chapter 8 and Næss (2009, forthcoming).

[19] See Yang (2005) for similar evidence from Beijing.

[20] This analysis was in itself carried out in two steps. First, a number of variables with non-significant relationships with energy use (p > 0.050) were eliminated, using a ‘backward elimination method starting with a full model (20 or 21 independent variables) and running repeated regressions where the variable with the weakest level of significance in the previous regression was each time eliminated. This procedure went on until only variables meeting a significance level of 0.05 remained in the model. Thereupon, in order to keep the number of respondents included in the analysis as high as possible, the analysis was run once again with only the significant variables. Several respondents had missing values on the variables that turned out with insignificant relationships with energy use and these respondents were excluded from the first step of thebackward elimination analysis even if they had valid values on all the remaining variables. Using this two-step procedure allowed keeping the number of respondents as high as possible in the final analysis. A transformation into logarithmic energy values was considered because the ‘raw’ energy use values showed a skewed distribution, also among the respondents who had actually used motorized modes of transport during the investigated week. Using logarithmic energy values, the distribution was close to normality. However, the mean predicted value based on the logarithmically transformed energy figures turned out to deviate considerably from the actual mean. Using ordinarily measured energy figures, no such deviation occurred. The analysis was therefore finally carried out without logarithmic transformation of the energy values.

[21] Whereas residential location close to downtown Hangzhou contributes to reduce commuting distances significantly (Beta = 0.258, p = 0.0000) and a similar, but weaker effect is found of proximity to one of the two second-order centers (Beta = 0.120, p = 0.0003), location of the dwelling close to one of the six third-order centers tends to increase the length of journeys to work (Beta = - 0.188, p = 0.0000). See Næss, 2007, pp. 246-251.