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Exploring commute mode choice in dual-earner households in a small Chinese city

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ABSTRACT

Most research on the impact of the built environment (BE) on travel behavior and residential self-selection (RSS) has focused at the individual rather than the household level. Using data collected in the small Chinese city of Ganyu, the present research explored how BE factors at spouses' residential and work locations influence their joint commute mode choice, and the extent to which RSS occurs. Based on the results of nested logit modeling, we found that spouses' travel mode choice is less related to residential BE factors and instead significantly associated with workplace accessibility. Moreover, we also found less evidence of RSS, which is related to individuals' residential preferences and travel environment in small cities. These findings suggest that the impact of BE on travel behavior and RSS is context specific, and that policies aimed at reducing traffic volume should differentiate between small and large Chinese cities.

1. Introduction

Commuting to and from work is one of the most important travel purposes in most people's daily lives and contributes to high volumes of car traffic and traffic congestion. Changing the built environment (BE) through urban planning is one effective tool to influence the generation of trips and reduce traffic congestion. For example, an individual is less likely to commute by car if there is a change in certain BE factors, such as increased density, diversified land use, the creation of a more walkable environment or reduced distances to public transit stops (Ewing and Cervero, 2001; Ewing and Cervero, 2010). As commuting takes place between residential and work locations, the BE at both locations could influence the mode choice for this trip.

Travel attitudes also influence an individual's travel behavior and are related to the process in which BE influences travel behavior. Travel attitudes are usually defined as the degree to which a specific travel mode is evaluated as favorable (Gärling et al., 1998). Many studies have shown that people with certain attitudes might select a residential location that suits their travel attitudes and preferences so that preferred travel modes can be used more frequently (Bohte et al., 2009; Cao et al., 2009; Kitamura et al., 1997); this process is called residential self-selection (RSS). In addition, people may adjust their travel attitudes based on their residential location, although evidence for this is still both scarce and inconclusive (Kroesen et al., 2017; Lin et al., 2017).

An additional factor determining the ways BE influences travel behavior is the fact that a household's residential location is not determined by a single individual but rather involves discussion and the participation of different household members (Tran et al., 2016). It is possible that the BE of a residential location suits one household member's needs and preferences but not the others. As a result, BE impacts the travel behavior of various household members differently. In addition, household members have to coordinate

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and distribute the use of household resources and jointly decide daily commute mode choices.

The occurrence of RSS has its own socioeconomic, cultural, and geographic backgrounds. The prevalence of RSS is mainly found in the West, where people who prefer to travel by car tend to live in suburban areas. However, as the socioeconomic, cultural, and geographic contexts are different in developing countries (e.g., China), RSS might therefore also be different. The extent to which RSS occurs in terms of different members within a household has not been thoroughly investigated in the Chinese context.

Travel behavior research in China has mostly addressed the issue in big Chinese cities; less attention has focused on small cities in China. Compared to big cities, small cities have lighter traffic, less developed public transportation (PT), and different travel behaviors (Handy et al., 2012; Hu et al., 2018; Hu et al., 2021). How the members of a household in a small Chinese city jointly decide their daily commute mode and how this relates to BE at the residential and work locations of its various members has remained unknown.

The present research aimed to narrow this gap by answering the following two questions:

(1) In dual-earner households, how do BE factors at residential and the work locations (i.e., density, diversity, destination accessibility, and design) influence the joint commute mode choice within a household?
(2) To what extent does RSS occur in dual-earner households in small Chinese cities?

Answering these questions extends our insights into the impact of BE on commute mode choice from the individual to household levels, and the extent to which RSS occurs in dual-earner households in small Chinese cities.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature on the impact of built environment on travel behavior, residential self-selection, and intra-household transportation research. Section 3 describes the data collection and modeling approach while Section 4 presents the descriptive analysis of the data and the modeling results to examine the extent to which RSS occurs in dual-earner households. A conclusion and a discussion are presented in the final part.

2. Literature review

2.1. The impact of the built environment on travel behavior and self-selection issue

Although sometimes people do travel for fun (Mokhtarian and Salomon, 2001), most trips are made in order to participate in various daily activities. As BE influences the characteristics of the transportation system and the distribution of activities over space, an individual's travel behavior is associated with the surrounding BE. Many studies have found that people who live in areas characterized by a higher population density, mixed land use, and a better walking environment tend to use active travel modes more frequently (Ewing and Cervero, 2001; Ewing and Cervero, 2010; Wang and Zhou, 2017). Moreover, the distance between place of residence and the city center also matters. This indicator reflects the urban structural situation of the residential location, which also influences travel behavior. The closer an individual lives to downtown, the more possible destinations there are for various activities (e.g., work opportunities or stores for shopping) (Naess, 2003). In this context, inner-city residents are more likely to travel shorter distances and use a car less frequently than their outer-area counterparts, a hypothesis that has been confirmed and evidenced by many European studies (Næss, 2006, 2010; Naess and Jensen, 2004).

In addition, an individual's commute behavior is influenced by the BE not only at a residential location, but also at a workplace—the location where an employee performs work-related activities. Zhang (2004) found that high job density at the workplace decreases the probability of driving and promotes commuting by foot, cycling and PT. Workplace accessibility also matters in commute mode choice. Wolday et al. (2019b) found that people who work far from the city center tend to commute by car. Many studies have also found that BE factors such as job and population density, road density, mixed land use, and distance to transit at both the residential and work locations influence an individual's commute behavior (Tran et al., 2016; van Acker and Witlox, 2011; Zhang, 2004; Zhao, 2013). Nonetheless, a few studies have shown that workplace BE has more impact than that at the residential location (Zhu et al., 2019). In particular, Chen et al. (2008) found that employment density at the work location played a larger role in influencing individual commute mode choice than residential density at the residential location. However, Sun et al. (2017) found that the BE at the residential location had more influence on commute behavior than that at the work location, and that people living in areas with a greater proportion of four-way intersections, a higher road density, and a higher population density were less likely to drive to and from work. The different conclusions might arise from different measurements and delineations of the BE at residential and work locations—which is known as the "modifiable areal unit problem" (Fotheringham and Wong, 1991). For example, BE factors in Sun et al. (2017) were measured at the sub-district level (administrative sub-district for each district) while BE factors in Chen et al. (2008) were measured at the census tract level. In addition, it should be noted that the survey data used in Sun et al. (2017) mainly came from respondents in a leisure park in Shanghai, which shows BE's impact on travel behavior for a certain sub-population only.

Besides, travel attitudes may indirectly influence an individual's travel behavior through location choice. RSS refers to the situation in which people with certain travel attitudes choose a residential location that corresponds with those attitudes, so that they can use preferred travel modes more frequently (Kitamura et al., 1997). However, the residential location decision is more complex than that, and travel attitudes may not be translated into a corresponding residential BE. The residential location choice is, for instance, constrained by housing prices and household affordability (Guan et al., 2020). Besides, people might also consider a number of additional factors such as neighborhood safety, the aesthetics of dwellings, and the social atmosphere and so might not give travel attitudes priority (Cao and Chatman, 2016; Ettema and Nieuwenhuis, 2017). If residential location choice is not based on travel attitudes and preferences, RSS will not occur.

RSS has its own cultural and socioeconomic background. In the West, car-based suburbanization leads to a car-oriented environment, which meets the wants and needs of households that prefer to travel by car. In particular, people who dislike the crowdedness and lifestyle in urban areas might choose to live in low density suburban areas and so drive more as a result. In addition, it is assumed that people who are RSS with respect to car use can actually afford a car, and that the environmental quality in suburban areas can meet the needs of those who prefer to live in low-density neighborhoods with green surroundings. However, the underlying contexts of RSS barely exist in developing countries such as China for the following reasons:

(1) Chinese cities have a higher land-use density than most Western countries. This is reflected in the differences in urban population density; urban population density in major Chinese cities ranges from 4×10^3 to $22 \times 10^3/km^2$, while in the USA it ranges from 0.3×10^3 to $2.4 \times 10^3/km^2$ (Tan et al., 2008; United States Census Bureau, 2016). Despite the tendency toward lower-density development patterns in the 1990 s, land-use policy in China has remained oriented toward high-density patterns, especially following the restrictions placed on land uses for villas on the periphery of urban areas since 2003 (Ministry of Land and Resources, 2003). This contributes to suburbanization with higher density and more mixed land use, which is different from that in Western countries.
(2) In China, car ownership is significantly lower than in the West. The car ownership rate in China is about 15%, which is much lower than in many Western countries (e.g., it is 63.5% in Italy, 55.5% in Germany, and 49.0% in the Netherlands) (European Environment Agency, 2018; Ministry of Public Security of China, 2019). In particular, some cities with large populations—such as Beijing, Shanghai, and Guangzhou—introduced a license plate lottery (i.e., the number of car registrations is limited) to control car ownership in those cities. Lower car ownership, together with high-density land-use policy in suburban areas, prevents the occurrence of RSS.
(3) As not many people use a car in China, individuals who can afford a car and prefer to travel by car are usually affluent, and they tend to live in urban rather than suburban areas (Yang et al., 2017; Zheng et al., 2005). This is related to the ongoing urbanization process in China, whereby the best education, medical resources, and other public services are mainly provided in central urban areas, which attract and meet the wants and needs of affluent people (Lan et al., 2018). Hu et al. (2021) explored the determinants of commute mode choice in a small Chinese city and found that its residents preferred to use a car more than rural residents. In addition, driving conditions were good throughout the city, even in the center, which does not restrict car use too much. Good driving conditions were reflected in the distribution of major trunk roads (i.e., the roads suitable for driving) in Chinese cities, which tends to be higher than that of other types of roads (Shi and Wang, 2007). In this context, people's residential preference, together with their driving preference and the driving conditions in Chinese cities, further reduce the tendency of RSS.

Recently, a few empirical studies have started to include travel attitudes in the analysis of the impact of the BE on travel behavior in China (Huang et al., 2016), but only some of them were involved in the exploration of RSS. In the Hangzhou Metropolitan Area study for example, Næss (2010) found that the differences in travel behavior between suburban and inner-city residents were independent of residential preferences and nearly unaffected by travel attitudes; thus, there was less evidence of RSS. In addition, Wang and Lin (2019), who used panel data from a two-wave survey in Beijing, found no evidence of RSS yet did find that travel attitudes were influenced by the BE at residential locations. Moreover, Lin et al. (2017) found reciprocal influences between residential BE and travel attitudes for residents in Beijing who were free to choose where to live.[1]

2.2. Households' role in the impact of the built environment on travel behavior

In a dual-earner household, the commuting mode choice of one spouse is influenced by the other spouse, especially in the case of car use. As the number of cars in a household is fixed, the use of the car by one spouse decreases the availability of the car for the other spouse, which in turn influences their travel mode choice (Kroesen, 2015). Hence, spouses have to negotiate the distribution of car use and jointly decide the commute mode. Many studies have confirmed that, in general, male spouses are more likely to use the household's car than female spouses (Anggraini et al., 2012; Anggraini et al., 2008). However, Habib (2014) found that, in dual-earner households with only one car, female spouses tended to use the car more than their partners if both spouses held driver's licenses.

BE has been found to play an important role in the allocation of a household's car and commute mode choices. For example, Anggraini et al. (2008) found that access to the workplace by car was the most important variable that influenced the car allocation decision in households. Maat and Timmermans (2009) found that in dual-earner families with only one car, the car was more likely to be allocated to the spouse with the longest commute distance and the lowest urban density at the work location (i.e., density index calculated by total density of housing, jobs and retail floor space).

In a household, the impact of BE on travel behavior may differ among household members (Yang et al., 2019). First, the allocation of household resources (e.g., cars) leads to the differing availability of travel modes, and the impact of BE is different for members with different levels of availability of each travel mode. For instance, for a household in a suburban area, BE may only facilitate car use for the household member who has access to a car. Second, the match or mismatch between travel attitudes and the residential location is another factor that explains the differences in the impact of BE on the travel behavior of household members. For the occurrence of RSS in a household, it is possible that the residential location choice is RSS for one spouse, but not for the other. In this context, residential

[1] These people buy houses rather than obtain government-allocated houses (e.g., Danwei houses).

BE might facilitate a certain travel behavior for one partner whose attitudes and preferences match the residential BE but might not have the same impact on the other partner whose travel attitudes are mismatched with it.

Although some research has focused on the impact of BE on travel mode choice at the household level (e.g., Janke, 2021; Maat and Timmermans, 2009), this issue was explored for each household member separately and did not consider the simultaneous impact of BE on household members' joint mode choice. As residential BE could influence the travel mode choice of couples simultaneously, it would be very interesting to investigate how BE exerts an impact on the travel mode choice of both spouses. In addition, very little research on BE's impact on travel mode choice at the household level has considered a possible RSS effect. Recently, Guan and Wang (2019a, 2019b) explored the impact of travel attitudes and BE on travel behavior among different household members. In particular, Guan and Wang (2019a) found that as distance to destinations from the residential location decreased, so did the share of travel by car for both spouses, but that this impact was slightly larger for males than for females after controlling for the travel attitudes of spouses.

2.3. Travel behavior in small cities

In travel behavior research, most evidence comes from larger cities; limited attention has been paid to smaller cities. This might be because traffic-related issues in small cities are less serious than those in larger cities. Compared with big cities, small cities do not have high population densities which suggests less traffic volume and less traffic congestion. Nevertheless, knowledge is required for researchers and planners of transport governance in small cities as there are certain traffic issues, such as traffic congestion, inadequate transportation infrastructure, and poor traffic management (Xiang et al., 2021). In small cities, PT systems are not well developed and not many residents choose PT for daily travel. A few studies showed that the PT share in small Chinese cities is less than 10% (Hu et al., 2018; Hu et al., 2021). Moreover, cycling or e-cycling is more prevalent than other travel modes in small cities (Handy et al., 2012; Hu et al., 2018; Hu et al., 2021). This might be because travel in small cities is usually over short distances, which is suitable for the use of bikes or electric bicycles (e-bikes).

Besides, very limited research has explicitly studied the association between BE and travel behavior in small cities. Using the data collected from the small Chinese city of Changting, Hu et al. (2018) found that not many BE factors play a significant role in influencing travel mode choice except land use diversity. In particular, they found that land use diversity at the work location is significantly associated with the commute mode choice on weekdays. In addition, regarding the attitudes-induced self-selection effect in land use–travel interaction research, Van Wee and Cao (2020) argued that people in small cities have less motivation for RSS, as there is less BE variation and less serious traffic congestion than in big cities. In Norway, for example, Wolday et al. (2019a) found that RSS in the Stavanger metropolitan area (pop. ~320,000) was less prominent than in the Oslo metropolitan area (pop. ~1 million).

3. Methodology

3.1. Research design

As we focused on household-level travel behavior, couples' joint mode choice was used as a unit of analysis. Within a household, it

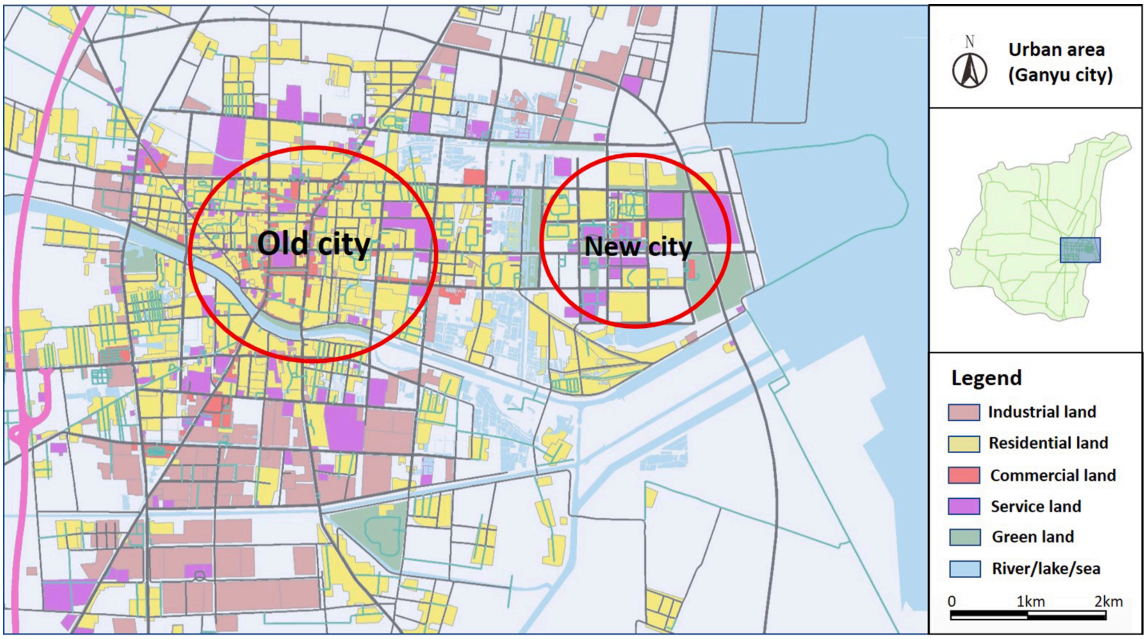

Fig. 1. Land use in Ganyu city.

is assumed that socioeconomic attributes and the BEs at the residential and work locations of each spouse could influence couples' joint mode choice. The BE factors used in our study are based on the 'Five Ds'—density, diversity, destination accessibility, design, and distance to transit—which are key factors that influence travel mode choice (Cervero and Kockelman, 1997; Ewing and Cervero, 2010). For 'density,' the number of points of interest (POI) of commercial facilities in each buffer was used to represent commercial density. Commercial POI is also a proxy for population density, as it can reflect how many people actually live, work or perform activities at a certain location. POI data is more accurate than registered population data, as some people might not reside or work at their registered address. For 'diversity,' the entropy index was used to measure the mixture of land use. Moreover, the Euclidean distance from a location to the city center was used to measure 'destination accessibility,' while also reflecting the urban structural situation of a location. In addition, different types of roads are related to design issues; as certain types of road infrastructure promote particular travel modes, we used the percentage of different types of roads to represent 'design.' Finally, as very few people in our sample used PT to commute, we did not use any indicators for 'distance to transit.'

Many BE variables suggest some possible correlations among them. For the variables with moderate or strong correlations (>0.5) (see Appendix A), a stepwise method was used in which we only put the variable that is significant and also contributes to the smallest value of the AIC (Akaike information criterion) or the BIC (Bayesian information criterion). For the detection of RSS, statistical control was used, which is illustrated in **3.5 Modeling approach**.

3.2. Data collection

The research area was Ganyu, a small city in the eastern part of China. The city covers an area of less than 100 km^2 and has about 200,000 inhabitants (Lianyungang Bureau of Statistics, 2018). The central urban area in Ganyu has two residential areas: the old city and the new city (Fig. 1). The old city is the city center, which has full and mature public service facilities, while the new city is newly constructed and has larger buildings and wider roads.

A survey was conducted in December 2019 to acquire household travel data. Local schools were contacted to help us collect data by asking students to invite their parents to participate in the survey. As we aimed to acquire travel information regarding both spouses in households, data collection through schools was an ideal and practical way to approach them. With respect to the geographical and age distribution of the respondents, four schools were selected for data collection, namely a primary school and a junior high school in the old city area, and two counterparts in the new city. Although our data do not represent the whole population in the study areas, they do provide insights into the impact of BE on the commuting patterns of a sub-population, namely working parents with children at school. It is very interesting to look into the travel behavior of these people as they lead busy lives, juggling their careers with raising children. In addition, the distribution of the four schools in the old and the new city ensured that data were collected from people living and working in different locations, which can be seen from the value of the standard deviation of the BE factors shown in Table 2.

Each student was given an envelope containing two questionnaires, one for the student's mother and the other for the student's father. As we wanted to collect both spouses' travel data, only households with both spouses living in Ganyu were invited to participate in the survey. The envelopes with completed questionnaires were returned to us. Some envelopes were returned with blank questionnaires, providing evidence that the survey was both anonymous and voluntary. Parents were clearly informed of the voluntary nature of participation in the survey and there was no way to link a returned envelope to any child.

In total, 2372 envelopes were distributed: 595 and 796 envelopes for the primary school and junior high school in the old city, respectively, and 406 and 575 envelopes for the primary school and junior high school in the new city, respectively. The questionnaire included questions about individual socio-demographics, household car/electric bicycle/bike ownership, daily main commute mode, attitudes toward various travel modes, and details of residential and work locations.[2] For an individual's commute choice, we asked about the primary and the most frequently used travel mode for commuting, in which 'primary' means the mode that was used for the longest duration during the trip.

The valid response rate was 55.9% (or 1325 households). A response was regarded as valid if both spouses in a household completed the entire questionnaire with differing handwriting styles. Although we cannot guarantee that the spouses completed the questionnaire independently, different handwriting styles provided evidence of independent participation, which contributed to reducing biases to a great extent. For further analysis, we identified 1000 dual-earner households. Based on this, we then excluded data provided by spouses who both chose to drive to work but owned only one car between them (a total of 13 households). Although such spouses could use their car in turns during the week, they obviously could not drive it at the same time. In addition, some household joint mode choices accounted for less than 1% of our sample. As such a low percentage is not suitable for modeling analysis, these observations were excluded. After screening, 984 dual-earner households were used for the empirical analysis. As shown in Fig. 2, respondents mainly lived in urban areas and they commuted to both urban and rural areas in Ganyu.

3.3. Travel attitudes measures

Travel attitudes were measured on a scale of 1 (strongly disagree) to 5 (strongly agree) in response to the following statements about each travel mode: 1) Car Attitudes: "I need a car to do some of the things I like to do"; "Getting to work without a car is a hassle"; "To me, a car is a status symbol; I like driving"; "Traveling by car is overall safer than cycling/e-cycling"; and "Traveling by car is

[2] The questionnaire contained more questions but only the questions used in this research are given here.

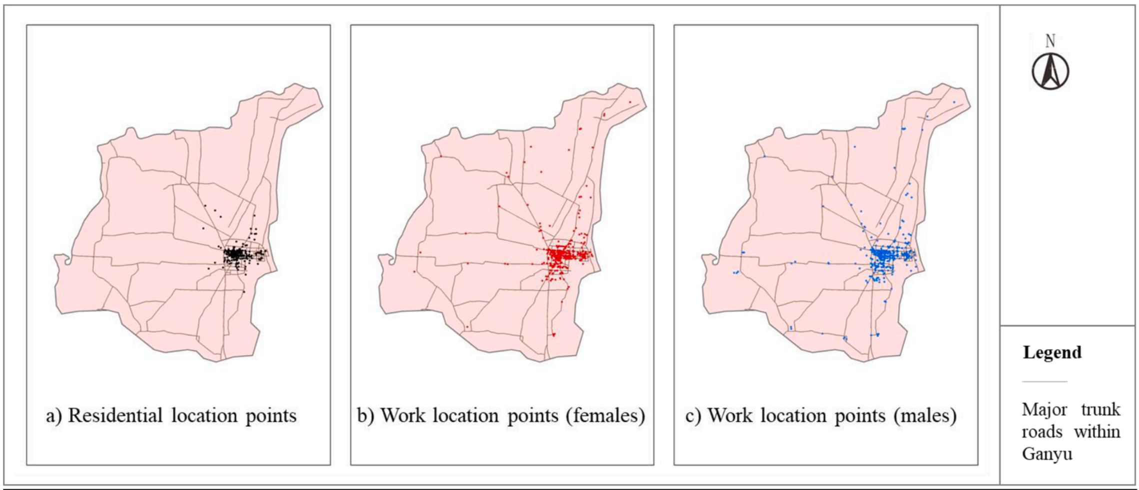

Fig. 2. Location points of residence and workplaces for females and males.

overall safer than walking." 2) Active travel attitudes: "I prefer walking to e-cycling"; "I prefer walking to driving"; "Walking is overall safer than e-cycling"; "I prefer cycling to driving"; "I prefer cycling to e-cycling"; "Cycling is overall safer than e-cycling." 3) E-bike attitudes: "I like riding an e-bike"; "E-cycling is easier for me than driving"; "E-cycling could help me reach the destination quickly"; and "E-cycling is more environmentally friendly". Specific attitude statements regarding active travel mode and car use come from Cao (2015) and Handy et al. (2005). As there are no validated statements regarding attitudes toward e-bikes, statements regarding attitudes toward e-bikes were based on the e-bike's attributes in the Chinese context, such as easy to ride, fast speed, and better accessibility to destinations (Cherry and Cervero, 2007; Weinert et al., 2007). We calculated the average scores of attitudes in three dimensions (i.e., car attitudes, e-bike attitudes, and active travel attitudes) to represent the attitudes toward each mode. Cronbach's alpha was used to test the reliability in each dimension: 0.87 for car attitudes, 0.85 for active travel attitudes, and 0.88 for e-bike attitudes for females, and 0.86, 0.86, 0.87 for attitudes toward these three travel modes respectively for males. All values of Cronbach's alpha for both males and females were higher than 0.85, which shows a good internal consistency of attitudes' items for each travel mode. The division of the three attitudinal dimensions was also verified by an exploratory factor analysis. In addition, travel attitudes toward buses were not included in the analysis, as the bus was a marginal travel mode choice—less than 6%—in the study areas.

3.4. Built environment factors

Following a study by Hu et al. (2021) in small Chinese cities, a 500-meter buffer around each household's residential and work locations of both spouses were made to capture the BE. The 500-meter buffer is also based on what Chinese people consider an acceptable walking distance (300–500 m) (Yang, 2018); here it is assumed that people's behavior would be more easily influenced by such walking distance buffers than by other distance buffers. BE factors included commercial POI density, land mix entropy, percentage of length for different types of roads (i.e., major trunk roads, secondary roads, and bike lanes), and Euclidean distance from residential and work locations to city center. The entropy index was calculated based on four types of land use—residential, commercial, industrial, and service—and was calculated as follows:

$$S = -\sum_{1}^{J} \frac{P_{jk} * In(P_{jk})}{In(J)}$$

where S refers to the entropy index,j represents the types of land use, and k denotes each observation; P_{jk} represents the percentage of land use j in total areas of land use in each buffer. The entropy index varies from 0 (homogeneous land use) to 1 (the most mixed land-use). Roads were classified into three types: major trunk roads, secondary roads, and bike lanes. Major trunk roads refer to arterial roads in urban areas and trunk roads across metropolitan areas. Major trunk roads can only be accessed by motorized vehicles. Secondary roads are inferior to major trunk roads and can be accessed by both motorized and non-motorized vehicles. Bike lanes are used only by bikes and e-bikes. We performed normalization with the length of each type of road by using the percentage of the length of each type of road in the total length of the road in each buffer.

3.5. Modeling approach

To assess the impact of the travel attitudes of both spouses and related BE factors on commute mode choice, as well examine the role of RSS, we applied the statistical control suggested by Mokhtarian and Cao (2008). This approach indicates the existence of RSS by making a comparison between two models, that is:

Table 1
Share of commute mode choice for females and males.*

Commute mode choice		Female (%)	Male (%)
Active travel	Foot	4.3	3.7
	Bike	1.4	1.5
E-bike	E-bike	63.4	22.2
Car	Car	23.2	62.4
Other	Transit bus	2.9	1.7
	Shuttle bus	3.3	3.8
	Motorcycle	1.5	4.8
Total		100	100

* Mode share distribution among the 984 dual-earner households.

Model 1) Commute mode choice $= f_1(BE_R, BE_F, BE_M, X) + \varepsilon$
Model 2) Commute mode choice $= f_2(BE_R, BE_F, BE_M, AT(females), AT(males), X) + \varepsilon$

Model 1 includes residential BE (BE_R), female spouse work BE (BE_F), male spouse work BE (BE_M), and socioeconomic attributes (X). Model 2 also includes the travel attitudes (AT) of both spouses in a household. If in Model 2 the effect of residential BE diminishes while travel attitudes contribute to more influence, travel attitudes are assumed to influence commute mode choice through RSS.

The joint mode choice of each pair of spouses was used as the outcome variable. In order to avoid too many alternatives in the choice set, four alternatives (active travel, e-bike, car, and other) were set for males and females respectively, leading to 16 (4 * 4) household joint mode choices. As mentioned, some household joint mode choices accounting for less than 1% of the total were removed from the data, and 13 alternatives (Table 3) were used as dependent variables in the final modeling analysis. Active travel refers to walking and cycling, car travel to driving to work and traveling by car, and other travel to shuttle bus, transit bus, and motorcycle (Table 1). In addition, Table 1 shows that more males commute by car (62.4%), while more females commute by e-bike (63.4%). Although the 62.4% car use among males seems to indicate rather high car ownership, if we calculate car use among the total number of our sample (both female partners and male partners), 42.8% of people choose to commute by car. This is understandable because our sample is only comprised of spouses from dual-earner households which tend to be wealthier than the average household in the research areas.

Choice sets varied between households depending on their own reporting of car/e-bike ownership and whether spouses held driver's licenses. Specifically, a car was considered available for an individual when the individual held a driver's license and the household owned at least one car. A car was also available for those who travelled by car (e.g., riding in another's car or a spouse's car). Others were available for those who took a shuttle bus or rode a motorbike to work, or if there was a transit bus route between an individual's residential and work locations. An e-bike was available for an individual when the household had at least one e-bike. If both spouses travelled by e-bike, the household had to own at least two e-bikes. It was assumed that everyone had access to active travel modes. Pandas Biogeme was used for the modeling estimation. The availability of each pair of joint travel modes for each household was considered in the syntax of the model, in which the availability is set as 1 if the pair of joint travel modes is available for a household; otherwise it is 0 (Bierlaire, 2020).

Our independent variables included household socioeconomic variables, BE, and travel attitudes (Table 2). As the age of both spouses in any one household was almost the same, we used the average value of both spouses' age to represent the age of each household.

For the modeling structure, 13 alternatives meant that there might be some correlations among them, and the nested logit model was chosen to capture the possible correlations. Different types of the nested structure were tested, and Mode(active active),[3] Mode (active e-bike), Mode(e-bike e-bike), and Mode(e-bike active) in the same nested layer was the most suitable (Fig. 3). This was further verified by the results of dissimilarity parameters of the nested layer of both models, which lie in the interval 0–1, as shown in Table 4 and Table 5.

4. Results

4.1. Descriptive analysis

4.1.1. Share and mode availability of joint commute mode choices

More households choose Mode(e-bike car) (39%) than Mode(e-bike e-bike) (15.8%), Mode(car car) (15.5%), or Mode(car e-bike) (5.3%), while other modes' shares are very small (<5%) (Table 3). This shows that in a small Chinese city such as Ganyu, females mostly choose e-bikes while males mostly choose cars. Travel mode availability refers to the percentage of couples who could access each type of joint mode choice. In particular, 82.4% of households could access Mode(active car), while 65.8% of households could access Mode(car active), which means that males have higher priority regarding car use than females.

[3] The form denotes how the household decides the joint mode choice, in which the left-hand choice within the parentheses is the female's choice and the right-hand one is the male's choice.

Table 2
Variables used in the model.

Variable	Percentage/ mean (std. dev.)			Explanation
Household socioeconomic variables				
Age				
25–35	24.6			Average age of spouses 25 to ≤35
35–40	37.3			Average age of spouses 35 to ≤40
>40	38.1			Average age of spouses >40
Education level				
F - High, M – High	56.8			F - Female spouse
F - High, M – Low	7.5			M - Male spouse
F - Low, M - High	11.2			High: College degree or above
F - Low, M - Low	24.5			
Annual Income				
F – Low, M - Low	10.8			Low: No college degree
F - Low, M - Mid	21.3			Low: < RMB 50k
F - Low, M - High	10.4			Mid: RMB 50k–100k
F - Mid, M - Low	1.8			High: ≥RMB 100k
F - Mid, M - Mid	30.3			
F - Mid, M - High	14.4			
F - High, M – Low	0.5			
F - High, M - Mid	2.7			
F - High, M – High	7.7			
Number of children				
1 child	17.3			
More than 1 child	82.7			
Built environment	**Residential location**	**F – work location**	**M – work location**	
Commercial POI (k/km^2)	0.69 (0.67)	0.80 (0.85)	0.50 (0.65)	
Land mix entropy	0.28 (0.11)	0.31 (0.14)	0.31 (0.15)	
Major trunk road (10%)	2.68 (1.48)	2.51 (1.43)	2.75 (1.64)	
Secondary road (10%)	6.18 (1.62)	6.56 (1.51)	6.60 (1.74)	
Bike lane (10%)	1.15 (0.72)	0.92 (0.84)	0.64 (0.77)	
Distance to city center (km)	2.10 (1.63)	4.29 (6.71)	6.42 (8.02)	
Travel attitudes	**Female**	**Male**		
Pro-active	3.06 (0.68)	3.12 (0.69)		
Pro-e-bike	3.91 (0.65)	3.40 (0.75)		
Pro-car	2.45 (0.75)	2.98 (0.80)		

Table 3
Distribution of household's joint commute mode choice.

Mode(Wife Husband)	Joint choice mode share (%)	Travel mode availability (%)
Mode(active active)	1.1	100.0
Mode(active e-bike)	1.1	97.6
Mode(active car)	3.5	82.4
Mode(e-bike active)	2.9	97.6
Mode(e-bike e-bike)	15.8	67.0
Mode(e-bike car)	39.0	80.0
Mode(e-bike other)	5.7	87.1
Mode(car active)	1.1	65.8
Mode(car e-bike)	5.3	63.5
Mode(car car)	15.5	21.2
Mode(car other)	1.3	58.9
Mode(other car)	4.5	70.0
Mode(other other)	3.3	77.2
Total	100	

4.1.2. Socioeconomic attributes

For age distribution, spouses with an average age of > 40 account for>50% of the choices of Mode(active active), Mode(active e-bike), Mode(e-bike active), and Mode(e-bike e-bike) **(**Fig. 4**-A)**, which shows that the active travel mode and e-bike are popular among older people.

With regard to education, spouses with high levels of education account for>70% of the choices for Mode(car active), Mode(car e-bike), and Mode(car car) **(**Fig. 4**-B)**. This means that if both spouses have higher education levels, they are more likely to use a car, or at least the females will use a car. This shows that highly-educated females will ask or compete with their spouses to use the only car in the household. Also, both spouses with high education levels accounts for>70% of Mode(other car) and Mode(other other). This is related

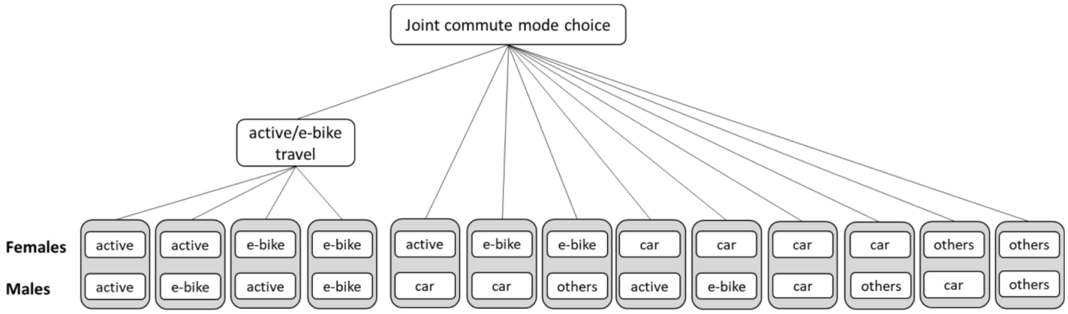

Fig. 3. Nested logit structure for joint commute mode choice.

to the socioeconomic attributes of the people in our sample who chose transit bus/shuttle and bus/motorcycle: a large number of these people were young, had a high level of education, worked in high-tech factories, and used company shuttle buses to get to work.

Both spouses with low incomes or households with low incomes for females and medium incomes for males account for>40% of the choices of Mode(active active), Mode(active e-bike), Mode(e-bike active), Mode(e-bike e-bike) and Mode(e-bike other) **(**Fig. 4**-C)**. This shows that the active travel mode and e-bike are more popular among the low- to medium-income group.

As the data were collected by way of schools, all households had at least one child. Households with more than one child dominate the share of most modes (>60%), except Mode(car active) **(**Fig. 4**-D)**. In Mode(car active), more than 50% were spouses with only one child in the household. In these households, wives were more likely to use the car, while husbands tended to walk and cycle. This is possibly because wives in one-child households are less burdened with household tasks than those in households with more children; they are more career oriented and engaged in higher qualified jobs for more hours per week, increasing the probability of commuting by car.

4.2. Modeling the residential self-selection effect

The results from Model 2 **(**Table 5**)** show how socio-economic attributes, BE, and attitudinal factors influence the joint mode choice in dual-earner households.

For the impact of socioeconomic attributes on mode choice, spouses aged 25–35 tend to choose Mode(e-bike car), rather than Mode (car car). One possible explanation is that younger couples have lower incomes and tend to have only one car. An additional explanation is that their children tend to be very young, which requires more care from the parents. In this context, female spouses spend more time on childcare and so choose to commute by e-bikes given their suitability for household maintenance activities in local areas (e.g., grocery shopping). In addition, spouses aged 35–40 tend to choose Mode(car car) rather than Mode(active e-bike). This shows that middle-aged residents are the main car users.

Couples with higher levels of education tend to choose Mode(car car) rather than Mode(active active). This shows that people with higher education levels—both female and male spouses—tend to use the car. Households with less-educated females but highly-educated males tend to use Mode(e-bike car), while households with highly-educated females but less-educated male spouses tend to use Mode(car e-bike). This shows that the car is usually assigned to the higher-educated spouse in a household, while an e-bike is allocated to the one with the lower level of education. Similar patterns also occur in the distribution of travel mode 'other' (i.e., transit bus/shuttle bus/motorcycling) and 'car' between spouses; highly-educated heads tend to choose other travel modes, while spouses with lower levels of education tend to use the car. Besides, couples with high levels of education tend to choose Mode(other other). This is mainly because a large portion of people who choose 'other' travel mode in our sample worked in high-tech factories and usually have higher education levels and commute by company shuttle bus.

Compared with couples with low-income females and a high/middle income males, spouses with high income for both tend to choose Mode(car car) rather than Mode(e-bike car). This suggests that the high/middle-income female partner has a higher priority when it comes to car use. In addition, in households with low-income females and high-income males, spouses will choose Mode(e-bike active) and Mode(e-bike e-bike) rather than Mode(car car). This might be related to the transforming norms in mode choice, whereby husbands choose the travel modes (i.e., active travel/e-bikes) similar to their wives' if their wives choose e-bikes, even though males have a higher income.

Based on the model results, we do not find many significant residential BE factors, which suggests a limited impact of BE at residential location. This is consistent with another study in a small Chinese city (Hu et al., 2018). For the BE factor at residential locations, a higher density of commercial POI facilitates the choice of Mode(active active) for spouses. The higher density of commercial POI at residential locations means more job opportunities, which leads to a more balanced jobs-housing relationship and a shorter commute distance. The presence of more secondary roads increases the probability of spouses choosing Mode(active car) and Mode(e-bike car) rather than Mode(car car). This suggests that more secondary roads at residential locations promote e-bike use, but this impact only applies to female spouses.

Table 4
Nested logit model for household’s joint commute mode choice (Model 1).

Female Male	active active coef. (*t*-stat.)	active e-bike coef. (*t*-stat.)	active car coef. (*t*-stat.)	e-bike active coef. (*t*-stat.)	e-bike e-bike coef. (*t*-stat.)	e-bike car coef. (*t*-stat.)	e-bike other coef. (*t*-stat.)	car active coef. (*t*-stat.)	car e-bike coef. (*t*-stat.)	car car	car other coef. (*t*-stat.)	other car coef. (*t*-stat.)	other other coef. (*t*-stat.)
Constant	−5.65 (−6.22)	−6.15 (−4.47)	−4.78 (−5.07)	−4.28 (−6.34)	−1.49 (−3.75)	−2 (−4.01)	−1.52 (−2.2)	−5.49 (−7.68)	−1.59 (−4.84)		−6.14 (−6.91)	−3.01 (−7.79)	−8.28 (−3.55)
Socioeconomics													
Age (ref.: > 40)													
25–35	——	——	——	——	——	0.51 (2.43)	——	——	——		1.56 (1.57)	——	——
35–40	——	−1.43 (−1.61)	——	——	——	——	——	——	——		1.47 (1.56)	——	——
Education level (ref. = F - Low, M - Low)													
F - High, M -High	−0.96 (−1.56)	——	——	——	——	——	−0.69 (−1.88)	——	——		——	——	1.71 (1.55)
F - High, M - Low	——	——	——	——	——	——	——	——	0.78 (1.52)		——	1.27 (2.4)	——
F - Low, M - High	——	——	——	——	——	0.56 (1.99)	——	——	——		1.73 (2.25)	——	——
Income (ref. = F - High, M - High)													
F - Low, M - Middle	——	——	——	——	——	0.43 (1.84)	0.65 (1.82)	——	——		——	——	——
F - Low, M - High	——	——	——	1.14 (1.77)	1.16 (2.5)	1.17 (3.42)	——	——	——		——	——	——
Number of children (ref. = 1 child)													
More than 1 child	——	——	——	——	——	——	——	−1.44 (−2.18)	——		——	——	——
Residential location													
Commercial POI	0.78 (2.13)	——	——	——	——	——	——	——	——		——	——	——
Secondary road	——	0.28 (1.51)	0.29 (2.13)	——	——	0.22 (3.21)	——	——	——		——	——	——
Female’s work location													
Land mix entropy	——	——	——	——	——	——	−3.15 (−2.24)	——	——		——	——	——
Major trunk road	——	——	——	——	——	——	——	——	——		——	−0.37 (−2.64)	−1.47 (−2.13)
Distance to city center	−0.53 (−2.5)	−0.66 (−3.12)	−0.32 (−3.48)	−0.48 (−3.81)	−0.44 (−5.61)	−0.38 (−7.93)	−0.49 (−4.55)	——	——		——	——	0.19 (2.42)
Male’s work location													
Major trunk road	——	——	——	−0.58 (−2.53)	——	——	−0.21 (−2.07)	——	——		——	——	−0.92 (−2.11)
Bike lane	1.41 (3.84)	1.16 (3.24)	——	2.15 (6.68)	0.73 (3.8)	——	0.38 (1.55)	1.48 (3.44)	——		——	——	2.4 (2.67)
Distance to city center	——	——	——	——	−0.2 (−3.73)	——	——	——	−0.54 (−4.82)		——	——	——
Dissimilarity parameter	0.81 (5.05)												

Sample size: 984.
Init log likelihood: −2190.46.
Final log likelihood: −934.13.
Rho-square: 0.58.
AIC: 1982.26.
BIC: 2261.08.
Mode(car car) is the base in the mode choice.
"——" refers to those variables not significant at $t > 1.5$, which were excluded from the model.

With regard to the impact of BE at female spouses’ work locations: if females work far from the city center, spouses tend to choose Mode(car car) rather than choose Mode(active active), Mode(active e-bike), Mode(active car), Mode(e-bike active), Mode(e-bike e-bike), Mode(e-bike car), or Mode(e-bike other). This suggests that females tend to choose the car if their work location is far from the city center. This is consistent with previous studies that show that workplace accessibility is an important factor influencing travel mode choice (Engebretsen et al., 2018; Wolday et al., 2019b). Moreover, if land use is more mixed, spouses will choose Mode(car car) rather than Mode(e-bike other). While this is difficult to explain, this shows that female spouses in households where both spouses use

Table 5
Nested logit model for household's joint commute mode choice (Model 2).

Female Male	active active coef. (*t*-stat.)	active e-bike coef. (*t*-stat.)	active car coef. (*t*-stat.)	e-bike active coef. (*t*-stat.)	e-bike e-bike coef. (*t*-stat.)	e-bike car coef. (*t*-stat.)	e-bike other coef. (*t*-stat.)	car active coef. (*t*-stat.)	car e-bike coef. (*t*-stat.)	car car	car other coef. (*t*-stat.)	other car coef. (*t*-stat.)	other other coef. (*t*-stat.)
Constant	−9.1	−2.13	−4.39	−3.51	3.64	−0.13	0.21	−0.25	0.34		0.05	3.87	−1.39
	(−2.29)	(−0.63)	(−1.81)	(−1.32)	(1.96)	(−0.09)	(0.1)	(−0.15)	(0.15)		(0.03)	(2.92)	(−0.49)
Socioeconomics													
Age (ref.: > 40)													
25–35	——	——	——	——	——	0.43	——	——	——		1.57	——	——
						(1.79)					(1.49)		
35–40	——	−1.29	——	——	——	——	——	——	——		1.66	——	——
		(−1.53)									(1.68)		
Education level (ref. = F - Low, M - Low)													
F - High, M - High	−1.3	——	——	——		——	−0.72	——	——		——	——	1.67
	(−1.96)						(−1.87)						(1.38)
F - High, M - Low	——	——	——	——	——	——	——	——	1.12		——	1.03	——
									(1.49)			(1.7)	
F - Low, M - High	——	——	——	——	——	0.74	——	——	——		1.96	——	——
						(2.3)					(2.32)		
Income (ref. = F - High, M - High)													
F - Low, M - Middle	——	——	——	——	——	0.45	0.76	——	——		——	——	——
						(1.73)	(2.06)						
F - Low, M - High	——	——	——	1.16	1.52	1.09	——	——	——		——	——	——
				(1.89)	(3.05)	(2.84)							
Number of children (ref. = 1 child)													
More than 1 child	——	——	——	——	——	——	——	−1.6	——		——	——	——
								(−2.27)					
Residential location													
Commercial POI	0.79	——	——	——	——	——	——	——	——		——	——	——
	(1.93)												
Secondary road	——	0.15	0.34	——	——	0.27	——	——	——		——	——	——
		(0.82)	(2.45)			(3.54)							
Female's work location													
Land mix entropy	——	——	——	——	——	——	−3.73	——	——			——	——
							(−2.54)						
Major trunk road	——	——	——	——	——	——	——	——	——		——	−0.27	−1.39
												(−1.9)	(−1.95)
Distance to city center	−0.65	−0.57	−0.37	−0.54	−0.56	−0.44	−0.59	——	——		——	——	0.21
	(−2.42)	(−2.8)	(−3.94)	(−4.23)	(−6.08)	(−7.71)	(−5.25)						(2.41)
Male's work location													
Major trunk road	——	——	——	−0.52	——	——	−0.18	——	——		——	——	−1.13
				(−2.32)			(−1.76)						(−2.34)
Bike lane	1.35	1	——	2.21	0.6	——	0.25	1.41	——		——	——	2.64
	(3.41)	(2.61)		(6.51)	(2.77)		(0.98)	(3.08)					(2.84)
Distance to city center	——	——	——	——	−0.21	——	——	——	−0.45		——	——	——
					(−3.69)				(−3.39)				
Female's travel attitudes													
Pro-active	0.86	1.43	0.73	——	——	——	——	——	——		——	——	——
	(2.03)	(2.85)	(2.52)										

(*continued on next page*)

Table 5 (*continued*)

Female Male	active active coef. (*t*-stat.)	active e-bike coef. (*t*-stat.)	active car coef. (*t*-stat.)	e-bike active coef. (*t*-stat.)	e-bike e-bike coef. (*t*-stat.)	e-bike car coef. (*t*-stat.)	e-bike other coef. (*t*-stat.)	car active coef. (*t*-stat.)	car e-bike coef. (*t*-stat.)	car car	car other coef. (*t*-stat.)	other car coef. (*t*-stat.)	other other coef. (*t*-stat.)
Pro-e-bike	1.57 (2.73)	——	0.65 (1.71)	1.17 (2.85)	0.94 (3.07)	1.05 (3.95)	1.84 (4.39)	——	−0.8 (−2.13)		——	——	——
Pro-car	−2.35 (−4.43)	−2.98 (−5.52)	−1.91 (−4.73)	−1.49 (−3.89)	−2.09 (−6.17)	−2.27 (−7.64)	−1.18 (−3.02)	——	——		——	−2.02 (−5.21)	−1.24 (−1.58)
Male's travel attitudes													
Pro-active	1.45 (3.13)	——	——	1.14 (3.86)	——	——	——	——	——		——	——	——
Pro-e-bike	——	0.86 (2.03)	——	——	0.6 (2.94)	——	——	——	1.43 (4.1)		——	−0.5 (−1.77)	——
Pro-car	−1.3 (−2.75)	−1.08 (−2.36)	——	−1.63 (−5.15)	−1.68 (−6.78)	——	−1.72 (−5.65)	−1.73 (−3.15)	−1.62 (−3.95)		−2.15 (−4.13)	——	−1.15 (−1.96)
Dissimilarity parameter	0.72 (4.85)												

Sample size: 984.
Init loglikelihood: −2190.5.
Final loglikelihood: −736.17.
Rho-square: 0.66.
AIC: 1654.34.
BIC: 2099.48.
Mode(car car) is the base in the mode choice.
"——" refers to those variables not significant at t > 1.5, which were excluded in the model except those variables kept in Model 1.

Fig. 4. Distribution of socioeconomic attributes among different joint mode choices.

the car tend to choose to work in more mixed land use areas than those in households where females use e-bike and males use other travel modes. Besides, if there is a higher percentage of major trunk roads at female spouses' work locations, spouses will not choose Mode(other car) or Mode(other other), but instead Mode(car car). This suggests that the presence of more trunk roads decreases the choice for the mode of other (i.e., transit bus, shuttle bus, motorbike) but promotes car use, which is understandable because major trunk roads are more suitable for car users.

For the impact of BE at male spouses' work locations: the higher percentage of bike lanes facilitates spouses to choose Mode(active active), Mode(active e-bike), Mode(e-bike active), Mode(e-bike e-bike), Mode(car active) rather than Mode(car car). More bike lanes at the workplace means more walkable and cyclable areas suitable for walking, cycling, and e-bike use. This also shows that a walking and cycling environment at the workplace significantly influences male spouses' choice for e-bike and active travel modes. Besides, the higher percentage of major trunk roads at male spouses' workplace decreases couples' choice for Mode(e-bike active) and Mode(e-bike other). This is understandable as major trunk roads are not friendly for the people who choose to walk, to cycle, or to travel by transit bus or shuttle bus. Moreover, if males' work locations are far from the city center, spouses tend not to choose Mode(e-bike e-bike) or Mode(car e-bike) but rather Mode(car car). This suggests that work location accessibility also matters for male spouses; if males work far from the city center, they tend to use the car.

Regarding the impact of travel attitudes, a high score on attitudes toward a certain mode encourages individuals, both males and females, to choose that mode. This is consistent with previous studies that found that positive attitudes toward a certain mode contribute to the choice of that mode (Beirão and Cabral, 2007; Heinen et al., 2011). In addition, higher scores on car travel attitudes decrease a household's probability of choosing active travel and e-bike. This shows that attitudes toward car travel and active travel compete with each other. Also, in households where females prefer e-cycling, couples tend to choose Mode(car car) rather than Mode (car e-bike). This is related to the difference in the female spouses' travel attitudes between households where both spouses use the car and those where only female spouses use it. In households where both spouses drive to work, females tend to occasionally use an e-bike for daily grocery shopping and have a preference for e-bike use. By contrast, for those spouses choosing Mode(car e-bike), daily grocery shopping could be fulfilled by males on e-bikes, which leads to females not using e-bikes and thus not having much of a preference for e-bike use.

The changing results of residential BE between Model 1 **(**Table 4**)** and Model 2 **(**Table 5**)** were compared to test RSS; only the coefficient of secondary roads for couples with choice for Mode(active e-bike) became insignificant, whereas the coefficient of other residential BE factors does not decrease or become insignificant after adding the variables of attitudes. This suggests a certain extent of RSS for the couples who choose Mode(active e-bike). The change of the coefficient of secondary roads at the residential location between Model 1 and Model 2 suggests that couples who prefer active travel mode or e-bike but dislike car may choose a residential location with more secondary roads to promote their choice for Mode(active e-bike); secondary roads are inferior to major trunk roads and so are more suitable for active travel modes or e-bikes. However, as only one residential factor's coefficient changes and that coefficient only changes from marginally significant to non-significant, the tendency of RSS is not very evident. The limited extent of RSS in our study aligns with Van Wee and Cao (2020) argument that people in smaller cities have less motivation for RSS.

5. Conclusion and discussion

Most research on the impact of BE on travel behavior has focused on the individual level and so has ignored intra-household interaction. Our study narrows this research gap by exploring how BE at the residential and work locations influence the commute mode choice of two-earner households in a small Chinese city. We also examined the extent to which RSS plays a role within households.

Due to the specific research context, our study provides more insights into travel behavior in small Chinese cities. That 39% of the couples in our sample chose Mode(e-bike car) reflects the popularity of e-bike use among females and of car use among males in local areas. The popularity of this joint mode choice might be a result of different commute distances and allocations of household tasks among different household members: Females usually have a shorter commute distance (e.g., 5.0 km on average in our sample); females also carry out many household tasks and activities, while males tend to be the main breadwinners and have a longer commute distance (e.g., 7.3 km on average in our sample). In this context, an e-bike is more suitable for a female's daily commute, while car use is more suitable for males. E-bikes are popular because of their attributes (e.g., quick and easy to ride, no problems with parking or traffic congestion, better affordability and lower travel costs than a car). These attributes match the travel demands of females in small cities, where daily activities (e.g., commuting, dropping off the children, and grocery shopping) involve shorter distances.

Based on the modelling results, spouses' workplace accessibility plays an important role in influencing couples' commute mode choice. For both female and male spouses, if their work locations are far from the city centre, they tend not to choose e-bike or active travel modes, but instead rely on the car. This is consistent with previous research in the European context (Engebretsen et al., 2018; Wolday et al., 2019b). A main reason behind this is that a long distance from workplace to the city center contributes to a long travel time; this makes residents choose the car for finishing this trip. In contrast, the impact of residential BE is more limited, as not many residential BE factors are significant in influencing a couple's joint mode choice. This comes from the specific travel environment in local areas: the driving environment tends to be good across most urban areas and there are no serious traffic congestion issues, so people even in the central urban areas may also choose to commute by car.[4] In addition, we found that couples' travel mode choice is

[4] This is evidenced by the average Euclidean distance from a residential location to the city center for car commuters (2.04 km) compared to non-car commuters (2.14 km) in our sample.

related to the different types of road infrastructure at the workplace: the presence of major trunk roads promotes car use, while more bike lanes facilitate active travel and e-bike use. However, such impacts are more evident for males than females.

We also found the limited extent of RSS. This is due to the specific socioeconomic, cultural, and environmental conditions in the study area. As China is urbanizing, the best-quality public service facilities (e.g., schools, shopping centers, and hospitals) are mainly located within central urban areas, and where housing prices tend to be higher (Lan et al., 2018; Yang et al., 2017; Zheng et al., 2005). This attracted affluent residents who tend to use the car.[5] As a result, people who prefer to drive do not self-select suburban areas to enjoy a better car-use environment. In addition, people who choose walking, cycling, or e-cycling tend to reside in central urban areas.[6] In this context, the residential built environment could hardly impact travel mode choice, as residents in central urban areas tend to use e-bikes or active travel modes, as well as cars. Such limited impact of residential BE also contributes to the limited impact of RSS.

The limited extent of RSS is consistent with an empirical study by Wang and Lin (2019) who, using two-wave panel data before and after residential relocation in Beijing, did not find signs of RSS during the residential relocation process. The underlying reason is related to the residential mobility trend in China, whereby not many people who prefer to drive choose to reside in a low-density suburban area. However, it has to be noted that because traffic congestion is, of course, more serious in big Chinese cities than in small Chinese cities, people who prefer to travel by car might be discouraged from living in the center of big Chinese cities.

This paper provides insight into the impact of BE factors on commute mode choice at the household level, as well into RSS in the context of a developing country. Our findings suggest that decisions about residential location and car ownership, and the impact of BE on travel, are context specific, implying that BE policies aimed at reducing car traffic may need to differentiate between large and small Chinese cities. However, there are some limitations to our research. First, the limited extent of RSS in our study might also be related to how BE is measured. In this research, BE was measured through specific factors, such as commercial POI and different types of road infrastructure. This differs from those Western studies which detected RSS through different types of neighborhoods such as high-density urban neighborhoods versus low-density suburban neighborhoods. Different measurements of BE may contribute to different findings. Secondly, in our attempt to detect RSS, we assumed that attitudes remain unchanged when people make a residential location choice. However, some recent research has indicated that people might change their attitudes when they relocate to a new residential location (De Vos et al., 2018; Van Wee et al., 2019). Finally, because our data were collected from the parents of local school students and we only studied the commute mode choice and RSS of a certain group of people, our findings are not representative of the whole population. These limitations, however, give some directions for future research. A random sampling survey process would lead to more insights into household travel patterns over the whole population. Moreover, a survey of the residential relocation process with the measurement of travel attitudes before and after residential relocation could be used to explore how RSS plays a role among different members of a household.

CRediT authorship contribution statement

Yang Hu: Conceptualization, Funding acquisition, Investigation, Data curation, Methodology, Writing – original draft preparation, Review & Editing. **Anae Sobhani:** Methodology, Formal analysis, Review & Editing. **Dick Ettema:** Conceptualization, Methodology, Formal analysis, Review & Editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Correlation matrix between built environment at residential location, female work location, and male work locationSig. codes: *p ≤ 0.050; **p ≤ 0.010

[5] This can be seen from the income distribution between car users and non-car users in our sample: 42.1% of non-car users' incomes are in the 0–50k RMB range (low-income group) compared to only 8.7% of car users with incomes in that range.

[6] This can be seen from the fact that the average Euclidean distance from a residential location to the city center for those people who commute by e-bike and active travel mode is about 1.98 km and 1.68 km respectively.

	Residential location						Female work location						Male work location					
	Commercial POI	Land mix entropy	Major trunk road	Secondary road	Bike lane	Distance to city center	Commercial POI	Land mix entropy	Major trunk road	Secondary road	Bike lane	Distance to city center	Commercial POI	Land mix entropy	Major trunk road	Secondary road	Bike lane	Distance to city center
Residential location																		
Commercial POI	1																	
Land mix entropy	0.30**	1.00																
Major trunk road	−0.47**	0.18**	1.00															
Secondary road	0.19**	−0.29**	−0.90**	1.00														
Bike lane	0.55**	0.30**	−0.05	−0.40**	1.00													
Distance to city center	−0.71**	−0.32**	0.52**	−0.23**	−0.55**	1.00												
Female-work location																		
Commercial POI	0.23**	0.10**	−0.13**	0.05	0.15**	−0.25**	1.00											
Land mix entropy	0.15**	0.07*	−0.14**	0.11**	0.03	−0.24**	0.02	1.00										
Major trunk road	0.01	−0.01	−0.02	0.06	−0.07*	−0.06	−0.30**	0.43**	1.00									
Secondary road	−0.11**	−0.03	0.08*	−0.08*	0.01	0.18**	−0.14**	−0.36**	−0.84**	1.00								
Bike lane	0.18**	0.08*	−0.10**	0.05	0.11**	−0.22**	0.77**	−0.09**	−0.19**	−0.37**	1.00							
Distance to city center	−0.22**	0.03	0.39**	−0.36**	0.02	0.36**	−0.39**	−0.27**	−0.33**	0.60**	−0.52**	1.00						
Male-work location																		
Commercial POI	0.21**	0.11**	−0.13**	0.06*	0.12**	−0.20**	0.13**	0.07*	0.04	−0.09**	0.10**	−0.13**	1.00					
Land mix entropy	0.13**	0.06	−0.16**	0.13**	0.04	−0.19**	0.10**	0.21**	0.11**	−0.16**	0.09**	−0.24**	0.22**	1.00				
Major trunk road	0.00	−0.03	−0.10**	0.13**	−0.07*	−0.07*	0.06	0.13**	0.18**	−0.22**	0.08**	−0.29**	−0.31**	0.32**	1.00			
Secondary road	−0.09**	−0.02	0.15**	−0.14**	0.01	0.17**	−0.11**	−0.16**	−0.20**	0.27**	−0.13**	0.36**	0.00	−0.29**	−0.90**	1.00		
Bike lane	0.19**	0.12**	−0.12**	0.05	0.13**	−0.23**	0.11**	0.09**	0.07*	−0.13**	0.12**	−0.19**	0.66**	−0.03	−0.10**	−0.34**	1.00	
Distance to city center	−0.20**	0.01	0.34**	−0.32**	0.01	0.31**	−0.17**	−0.26**	−0.22**	0.31**	−0.18**	0.57**	−0.30**	−0.30**	−0.40**	0.59**	−0.48**	1.00

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