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Factors affecting car ownership and mode choice in rail transit-supported suburbs of a large Chinese city

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ABSTRACT

As Chinese cities continue to grow rapidly and their newly developed suburbs continue to accommodate most of the enormous population increase, rail transit is seen as the key to counter automobile dependence. This paper examines the effects of rail transit-supported urban expansion using travel survey data collected from residents in four Shanghai suburban neighborhoods, including three located near metro stations. Estimated binary logit model of car ownership and nested logit model of commuting mode choice reveal that: (1) proximity to metro stations has a significant positive association with the choice of rail transit as primary commuting mode, but its association with car ownership is insignificant; (2) income, job status, and transportation subsidy are all positively associated with the probabilities of owning car and driving it to work; (3) higher population density in work location relates positively to the likelihood of commuting by the metro, but does not show a significant relationship with car ownership; (4) longer commuting distance is strongly associated with higher probabilities of riding the metro, rather than driving, to work; (5) considerations of money, time, comfort, and safety appear to exert measurable influences on car ownership and mode choice in the expected directions, and the intention to ride the metro for commuting is reflected in its actual use as primary mode for journey to work. These results strongly suggest that rail transit-supported urban expansion can produce important positive outcomes, and that this strategic approach can be effectively facilitated by transportation policies and land use plans, as well as complemented by timely provision of high quality rail transit service to suburban residents.

1. Introduction

China's urbanization is continuing at a fast pace: between 2015 and 2030 its urban population is expected to increase by 230 million (China News, 2015; EastDay.com, 2015). One major challenge that Chinese cities have been facing for the last two decades, and will continue to face in the foreseeable future, is to provide satisfactory transportation that supports fast-paced urban growth and suburbanization, while striving to reduce traffic congestion, air pollution, and greenhouse gas emission. In response to the challenge, the large cities have uniformly adopted the strategy of constructing an extensive rail transit system to help meet growing travel demand and lessen automobile dependence. More than twenty cities now have a metro system in operation, and several dozens more cities are currently constructing, planning, or proposing such a system (Luan et al., 2014).

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Building a rail transit system to support urban growth is not a novel idea. Starting with London in 1863, many cities in the world have built metro systems and other forms of rail transit. Nonetheless, rail transit remains a highly controversial subject, as scholars disagree on whether it is an efficient system to satisfy urban residents' demand for mobility or to help cities achieve transportation-related environmental and social objectives (Baum-Snow and Kahn, 2005; Kain and Liu, 1999; Lave, 1998; Litman, 2007; Nelson et al., 2007; Voith, 2005; Winston and Maheshri, 2007; Zaretsky, 1994). Theoretically, the economic performance of a rail transit system depends critically on traffic volume and residential density (Meyer et al., 1965; Small and Verhoef, 2007). The great importance of these contextual factors suggests that empirical examination is often required to understand whether rail transit works well in a particular setting.

Gaining an understanding of the effects of rail transit development in China is imperative, because many cities—in China, as well as in other developing countries—are following this strategy without sufficient knowledge about the outcomes. This paper utilizes travel survey data from Shanghai to gain insights into how residents in rail transit-supported suburbs make choices regarding car purchase and, more importantly, transportation mode. The research focuses on suburban locations because the anticipated population growth in Chinese cities will mostly be accommodated in such locations. Here we generally define "rail transit-supported urban expansion" as urban growth that takes place in locations beyond the existing central city and that draws upon accessibility provided by rail transit, typically a metro system. To successfully facilitate sustainable development, rail transit-supported urban expansion must be a viable alternative to automobile-dependent urban expansion.

This paper presents an empirical study of the effects of rail transit-supported urban expansion in China, based on data for Shanghai. The research aims to answer three questions. First, what are the car ownership and modal choice characteristics of residents living in suburban areas near metro stations? Second, what factors are associated with suburban residents' car ownership status? Third, what factors are associated with suburban residents' commute mode choice? In addition to proximity to metro stations, socio-economic variables, built environment features, and attitudinal factors are considered in this analysis.

2. Literature review

Several bodies of literature are highly relevant to this research, and selected publications in each are reviewed here. One body of literature is on urban growth, suburbanization, and transportation challenges for cities in China. Another, drawn primarily from contributions by American and European researchers, presents competing perspectives on rail transit development as a response to urban transportation problems. A third strand of literature examines factors influencing people's car ownership decision and travel mode choice.

2.1. Urban growth, suburbanization, and transportation challenges for Chinese cities

China's urban population has been growing at an extraordinarily pace for the past three decades. In 1990 only less than 27 percent of its population lived in cities and towns, but in 2013 almost 54 percent resided in cities and towns. This doubling of urbanization level represents an additional urban population of over 400 million!

The rapid growth of urban population in China has been accompanied by continuous spatial transformation of cities. The built areas have greatly expanded, typically more than tripled since 1990. In the large cities, population growth has taken place primarily in newly developed suburban areas, accelerating the suburbanization process that started in the 1980s (Zhou and Meng, 1998).

The fast-paced urban growth and suburbanization have presented major challenges to urban transportation planners and policymakers. The rapidly increasing population, together with steadily increasing trip distances, has resulted in an ever rising travel demand that often overstrains existing transportation infrastructure and aggravates traffic congestion. Moreover, the urban spatial transformation has made automobiles an increasingly attractive, or necessary, mode of travel. In 1990 few Chinese households owned automobiles, but rapid income growth in China enabled motorization to quickly pick up pace (Gakenheimer, 1995; Shen, 1997). Less than twenty years later, in 2009, China became the world's largest automobile market. The most recent official statistics indicate that the number of passenger cars in the country has already passed 100 million, more than 50 times the number for 1990 (China Bureau of Statistics, 2014).

The combination of urban expansion and motorization will lead to automobile dependence unless some viable transportation alternatives become available to suburban residents. As a counter-measure to motorization and as a response to various transportation-related environmental and social issues, since the early 2000s the Chinese government has been emphasizing the importance of public transportation. Accordingly, large cities have gradually shifted their investment priority from highways and roads to rail transit. Facing serious challenges in providing mobility and in reducing emissions, planners and policymakers in China see rail transit as the key to solving transportation problems.

There are good reasons for being optimistic about what a rail transit system can bring to a city. A metro system can moderate accessibility loss resulting from relocation from central city to outlying areas and encourage many suburban residents to travel by rail instead of automobile (Cervero and Day, 2008). It also provides an opportunity for creating a multinuclei form of compact development with high-density suburban clusters around metro stations (Yang et al., 2012). Such a clustered spatial pattern of urban growth and suburbanization can help avoid, on the one hand, aggravated traffic congestion that would result from featureless expansion of dense central-city area (Yang et al., 2012), and on the other hand, substantially increased car use that would result from dispersed suburban development with a low degree of mixed land use (Zhao, 2010). Furthermore, rail transit can facilitate transit-oriented development and high-intensity land use near stations, reinforcing its share as a travel mode (Cervero and Day, 2008; Pan and Zhang, 2008). While many positive results of rail transit development are conceivable, there are also potential concerns, as suggested by the body of literature discussed next.

2.2. Competing perspectives on rail transit

Having witnessed a long history of rail transit development, American and European researchers have produced a large volume of literature discussing the merits and shortcomings of this type of urban transportation systems. The publications present sharply divided views. For the proponents, rail transit provides an opportunity for increasing public transportation ridership, reducing car use, and promoting social equity and environmental sustainability (Litman, 2007; Nelson et al., 2007; Voith, 2005; Zaretsky, 1994). For the critics, on the other hand, rail transit is an inefficient mobility system for most cities, as well as an ineffective way to reduce congestion, improve public transportation, or achieve environmental objectives (Kain and Liu, 1999; Lave, 1998; Winston and Maheshri, 2007).

Positive impacts of rail transit identified in the literature include, first, increasing or sustaining public transportation use, which is more likely to be replaced by single-occupancy driving where rapid transit is not available as an alternative (Baum-Snow and Kahn, 2005; Voith, 2005). Secondly, rail transit creates important social values by enabling people who are dependent on public transportation to travel by a speedy mode (Baum-Snow and Kahn, 2005; Litman, 2007). Thirdly, a metro system is more effective than a bus system in reducing traffic congestion because, unlike buses, subways and elevated rails do not compete with cars for limited road space (Nelson et al., 2007; Voith, 2005). Fourthly, energy consumption and emissions per passenger mile for rail transit is much lower than those for driving, which can lead to substantial environmental gains (Zaretsky, 1994). Finally, some rail transit systems, for example, the metro system in Washington DC (see Nelson et al., 2007), are shown to be able to generate net economic benefits. Moreover, rail transit produces a wide range of benefits, which, if fully considered, will often show the system to be cost effective (Hass-Klau et al., 2004).

Criticisms of rail transit include, first, below-forecast ridership (Kain, 1999) and high percentages of users from former bus passengers, which often constitute 70–75 percent of rail transit ridership (Lave, 1998). Secondly, negative impacts on social equity often result from developing rail transit, because public transportation agencies tend to allocate growing shares of available subsidies to constructing and operating rail systems while abandoning their successful policies of improving bus service and reducing bus fares (Kain and Liu, 1999). It is the bus—not rail transit—that benefits mostly the poorest urban residents (Winston and Maheshri, 2007). Thirdly, using rail transit to achieve environmental goals often has an ambiguous effect (Winston and Maheshri, 2007), or is simply wasteful (Lave, 1998). Fourthly, a rail system is inflexible and increasingly unsuited to meet urban residents' transportation needs, given the prevailing lifestyles and metropolitan land use patterns (Lave, 1998; Baum-Snow and Kahn, 2005). Finally, some researchers, including Winston and Maheshri (2007), show that almost all rail transit systems incur costs that substantially exceed benefits.

Obviously, supporters and detractors make many conflicting observations and arguments. What may help resolve the controversies is an analytical framework for measuring and comparing the performances of alternative transportation systems, including rail transit, in a given urban context. As an example, scholars have studied the relative economic efficiency of competing urban mobility systems and identified traffic volume in a corridor, along with the surrounding residential densities, as the key determinants (Meyer et al., 1965; Small and Verhoef, 2007). While this approach may have too narrow a focus, the general idea of examining more closely the relative merits of rail transit in light of the characteristics of a particular city seems quite promising. Indeed, most researchers from both sides of the debate acknowledge the importance of various socio-economic, built environment, and public policy factors in influencing the outcomes (Baum-Snow and Kahn, 2005; Hass-Klau et al., 2004; Kain, 1999; Litman, 2007; Nelson et al., 2007; Winston and Maheshri, 2007; Zaretsky, 1994).

Such an approach implies that carefully designed, context-sensitive empirical research must play a critical role in evaluating rail transit. A metro system may not be suitable for the typical American city where transportation corridors do not generate enough trips to make it financially competitive, but may work well for a few densely populated cities, such as New York and San Francisco. Chinese cities, and cities in most other developing countries, tend to have high population and employment densities and, hence, provide a favorable setting for efficient operation of a metro system. Examining closely what differences such a system actually makes to suburban residents' travel behavior is essential for advancing the knowledge and practice of rail transit-supported urban expansion. Car ownership and, more importantly, mode choice, are key indicators.

2.3. Factors influencing car ownership decision and travel mode choice

When an individual relocates residence, it is a major event in this person's life course, which is often associated with changes in travel behavior (Bamberg, 2006; Scheiner and Holz-Rau, 2012). Studies conducted in European cities find that positive changes in the forms of lower car ownership and more public transportation use can be induced by relocation and favorable changes in the built environment and transportation policy (Bamberg, 2006; Scheiner and Holz-Rau, 2012).

For households moving to the suburbs of a Chinese city from elsewhere, such as central city neighborhoods or rural villages, the relocation certainly is a major event in each household member's life course. At the new suburban residential location, significant changes in travel behavior will likely take place, and the default would be higher levels of car ownership and lower modal shares for public transportation, bicycling, and walking. But the construction of an extensive metro system provides an important opportunity for making positive changes instead, because people who have relocated to suburban neighborhoods near metro stations can travel by rail rather than car (Cervero and Day, 2008; Pan et al., 2011).

While proximity to metro stations is shown to be an important determinant of mode shift to rail transit (Lindsey et al., 2010; Kwoka et al., 2015), other factors likely also influence suburban residents' car purchase decision and travel mode choice. The existing literature presents strong evidence showing that socioeconomic factors, such as income, gender, age, and household characteristics affect car ownership and mode choice (Creemers et al., 2012; Hess and Ong, 2002; Nolan, 2010; Prillwitz et al., 2006; Van Acker and Witlox, 2010). Income, in particular, is identified by many researchers as a most significant predictor (Dargay et al., 2007; Prillwitz et al., 2006; Schimek, 1996).

The literature also includes a large volume of empirical research on the effects of built environment factors. Many studies find that density, land use mix, and street layout influence people's decisions on whether to purchase a car and how to get to a trip destination (Bergman et al., 2011; Bhat and Guo, 2007; Hess and Ong, 2002; Li et al., 2010; Potoglou and Kanaroglou, 2008; Senbil et al., 2009; Van Acker and Witlox, 2010). Moreover, built environment characteristics in both trip origin and destination matter, and some studies show that workplace built environment variables provide more explanatory power for mode choice than those of home locations (Chen et al., 2008; Kwoka et al., 2015; Shiftan and Barlach, 2002). In addition, individuals tend to show a stronger preference for rail transit and driving over other travel modes when the trip distance gets longer (Limtanakool et al., 2006). However, there is no consensus on the importance of the built environment in shaping travel behavior.

One important source of disagreement on the effects of the built environment is the interplay between residential location choice and travel behavior (De Vos et al., 2012; Mokhtarian and Cao, 2008). This interplay causes the self-selection problem, as individuals select themselves into preferred built environments rather being distributed randomly. This makes it difficult to assess the true effects of built environment factors on whether household buy cars or how individuals travel. Researchers have designed various methodological approaches to address the self-selection problem, and some researchers have shown that the built environment remains a significant determinant of travel behavior (Cao, 2009; Ewing and Cervero, 2010; Hong et al., 2014).

One effective way to tackle the self-selection problem in travel behavior analysis is to include in the regression model explanatory variables that measure individuals' attitudes toward transportation alternatives (Handy et al., 2005; Hong et al., 2014). These attitudinal variables are typically quantified using data collected through a travel survey. Some researchers find that people's attitudes are a more powerful predictor of travel behavior than the built environment (Olaru et al., 2011).

To be sure, there are other determinants of car ownership and mode choice. Some of them are historical and cultural factors that are unique to particular contexts (Senbil et al., 2009). These factors are conceptually important, although they tend to be less tangible and, hence, are rarely included in empirical analysis.

3. Research design

3.1. Study areas and data

To examine the effects of rail transit on suburban residents' car ownership and modal choice, we decided to undertake an empirical study of Shanghai, China's largest and economically most important city. According to the most recent census, Shanghai's population was 23 million in 2010 (China Bureau of Statistics, 2011). During the decade of 2000–2010, the city's suburban areas grew rapidly and accommodated much of the population increase, which is quite representative of suburbanization trends observed in most Chinese cities. Shanghai has been playing a leading role in the practice of rail transit-supported urban growth. Although its first metro line started operation only 20 years ago, its metro system today is one of the world's largest with 14 lines, over 300 stations, an extensive network, and a daily volume of 8 million passengers. Fig. 1 shows the rapid expansion of Shanghai metro system from 2003 to 2010.[1]

The metro system has quickly become a significant travel mode for residents in Shanghai, as shown in Table 1. In 2004, rail transit accounted for only 2.9 percent of all trips for the whole city and 4.3 percent for the central area (defined as the geographic area inside the "out-ring expressway", which is shown as the shaded area in Fig. 1). In 2014, its mode share reached 9.0 percent for the whole city and 14.7 percent for the central area. Mode shares have also significantly increased for automobile and E-bicycle, but decreased for bus and bicycle. However, these aggregated figures do not tell us the extent to which the metro system has changed the travel behavior of suburban residents who live near metro stations.

Due to resource constraints, we selected four representative residential areas located in Shanghai's suburbs for the empirical work (Fig. 2(a)). Three of the selected study areas, Gongfuxincun, Jiuting, Xinzhuang, are situated near metro stations, whereas the fourth one, Jinqiao, is not proximate to rail transit. Household travel surveys were conducted in these neighborhoods in 2010 and 2011 to collect data on car ownership status, commuting mode choice, home and work locations,

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[1] The 2010 metro network—rather than a more recent one—is shown here because the travel data used for this research was collected by household surveys conducted in 2010 and 2011.

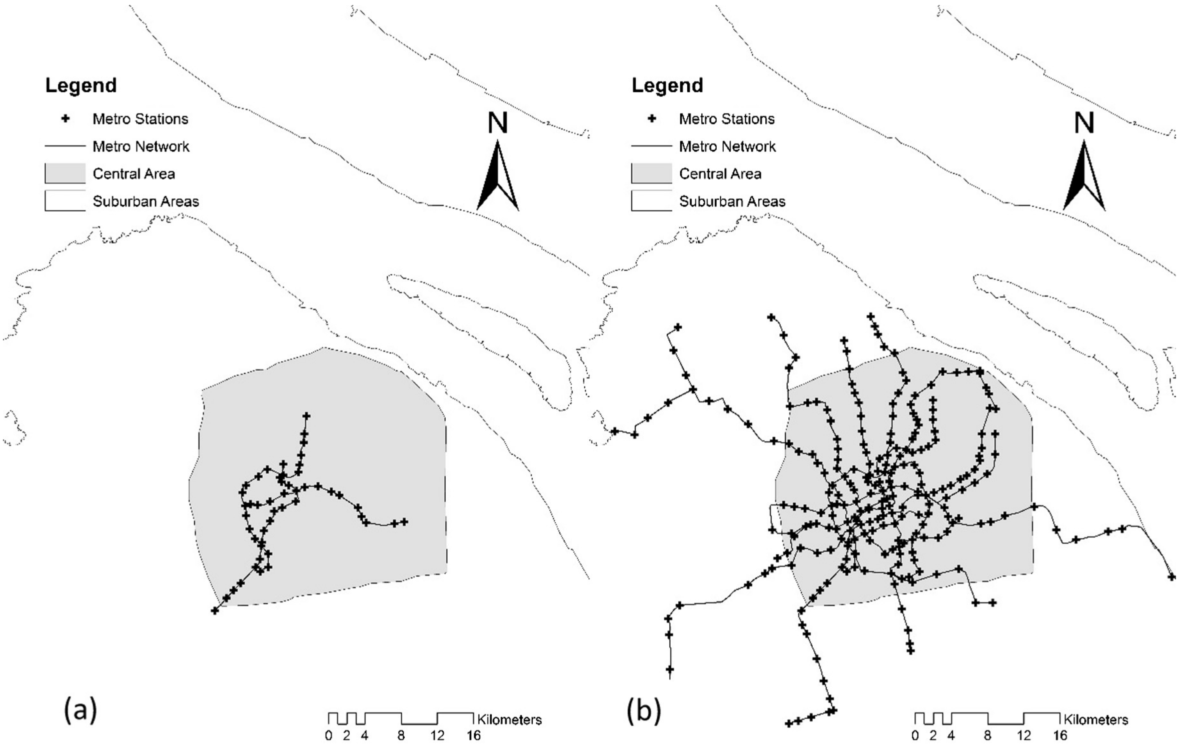

Fig. 1. Rail transit system of Shanghai in 2003 (a) and 2010 (b).

Table 1
Transportation mode choice of Shanghai residents, 2004–2014. *Source:* Shanghai Municipal Government (2015).

Year	2004		2009		2014	
	Whole city (%)	Central area (%)	Whole city (%)	Central area (%)	Whole city (%)	Central area (%)
Rail	2.90	4.30	5.70	8.70	9.00	14.70
Bus	14.70	20.80	12.90	17.10	12.60	16.80
Taxi	7.00	9.20	6.60	8.80	4.60	6.40
Auto	11.60	12.00	15.40	18.90	16.70	17.50
Motorcycle	6.20	1.10	4.60	0.60	1.70	0.30
E-bicycle	5.30	4.40	15.20	9.50	20.40	12.10
Bicycle	25.00	18.30	13.50	10.00	7.30	6.90
Walk	27.30	28.90	26.20	26.50	27.70	25.30

demographic characteristics, and occupation and income.[2] In light of the importance of attitudinal factors in location and travel decisions, we included several questions in the survey to collect data on respondents' intention to use metro as primary commuting mode when relocating to current neighborhood, as well as their considerations of monetary cost, time savings, safety, and comfort in choosing commuting mode. The questionnaire was filled by a randomly selected sample of households and their members. The surveys resulted in valid data for 823 households and 1436 individuals. As shown in Fig. 2(b), the respondents' workplaces are widely distributed in the metropolitan area although most are in central locations of Shanghai.

Built environment was measured using GIS land use data and population census data for 2010. Land use variables were quantified for each respondent's home and work locations. These variables include population density for work location, land use mixture for both home and work locations, and distance to the closest metro station for both home and workplace. Population density for home location is not included because it has little variance for a sample drawn from only four residential neighborhoods. An additional measure of the built environment is commute distance for each working individual, which is estimated by the shortest path between home and workplace.

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[2] In the sample used for this study, households in Gongfuxincun, Jiuting, and Xinzhuang are all located within 2 km from the closest metro station, whereas households in Jinqiao are all located beyond 2 km. It is also useful to mention that, three years after the household travel surveys were conducted Jinqiao became proximate to the metro due to the extension of the rail transit system.

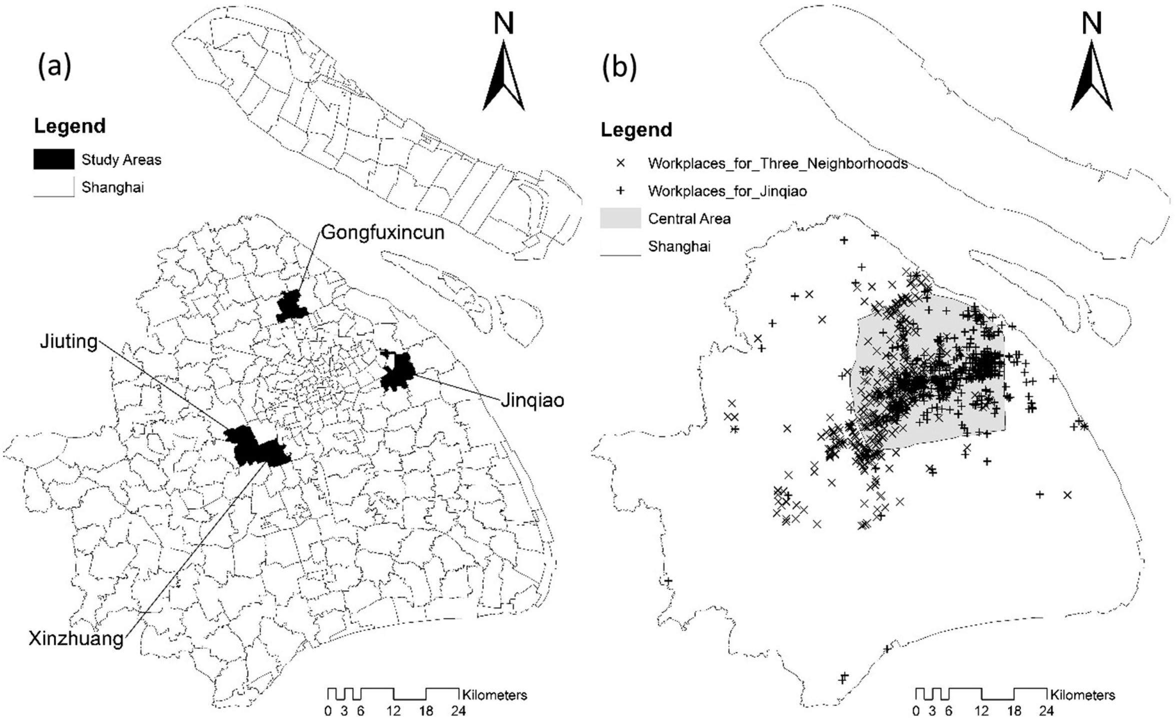

Fig. 2. Four study areas (a) and spatial distribution of respondents' workplaces (b).

The resulting dataset consists of about two dozens of variables. Table 2 displays these variables, which are grouped into four categories, as well as their definitions. Note that many of these variables are measured at both individual and household levels. Income and subsidy for household are the sums for individual household members. Gender, occupation type, and attitudes for household are measured by the mean values for individual household members. Household rail transit proximity and commuting distance are assigned the maximum values for individual household members, whereas household workplace population density and land use mixture are assigned the minimums. These maximum and minimum values are conceptually related to household's greatest need for owning a car.

3.2. Model specification

To address the second and third research questions, regression models are estimated to explain household car ownership status and individual commute mode choice. The large volume of literature on car ownership decision and travel mode choice, which includes some recent studies in the context with rail transit as an option (Bergman et al., 2011; Creemers et al., 2015; Forsey et al., 2013), provides rich references for model specification. Typically, the regression models incorporate a discrete choice framework and use relevant socio-economic, attitudinal, and built environment factors as independent variables. For our empirical examination, the car ownership model takes the simple binomial logit form, expressed as Eq. (1):

$$\ln\left(\frac{P_i}{1-P_i}\right) = \alpha + \beta_j X_{ij} \tag{1}$$

where P_i is the probability of household i owning one or more cars; X_{ij} is the vector of independent variables associated with the decision of car purchasing, α is intercept, and β_j is the vector of corresponding parameters. The independent variables used to explain car ownership status include socio-economic, attitudinal, and built environment measures quantified at the household level.

Commuting mode choice is also modeled by applying the discrete choice framework. Six primary transportation modes are identified for this research: walk, bike, E-bike, bus, rail, and car. Given these modes, the "independence of irrelevant alternatives" (IIA) property of the multinomial logit model may not hold because several modes are substitutes to some extent. Specifically, bus and rail transit are not independent choice alternatives; nor are bike and E-bike. Therefore, the multinomial logit model may not be appropriate. Instead, we employ a nested logit model, which specifies a hierarchical structure of the choice alternatives such that IIA holds within each branch ("nest") of alternatives but not across branches (Train, 2003). In this case, "bus and rail transit" and "bike and E-bike" are treated as two nests of alternatives, whereas "walk" and "car" are independent alternatives. Thus, the resulting hierarchical structure has four branches of alternatives, as shown in Fig. 3.

Table 2
Variables and definitions.

	Variables	*Definitions*
Dependent variables	Car owner	Household car ownership status, 1 for yes, 0 otherwise
	Commuting mode	Six primary modes were coded: walk, bike, E-bike, bus, rail, and car; 1 for selected mode, 0 otherwise
Socio-economic factors	Gender	1 for male, and 0 for female
		for household, mean value ranging from 0 (all members female) to 1 (all members male)
	Age	Age of respondent, in years
	# of employees	The number of employees in household
	# of children	The number of children in household
	# of seniors	The number of retired people in household
	Income	Annual income of respondent, in 10^3¥
		for household, sum of members' incomes, in 10^3¥
	Employment type	1 for jobs that tend to have flexible commuting schedules, including government officials, enterprise executives, and business owners; 0 otherwise
		for household, mean value ranging from 0 to 1
	Subsidy	Monthly transport subsidy provided by employer, in 10^3¥
		for household, sum of members' subsidies
Attitudes	Safety	1 for selecting a mode because it is safe, 0 otherwise
		for household, mean value ranging from 0 to 1
	Comfort	1 for selecting a mode because it is comfort, 0 otherwise
		for household, mean value ranging from 0 to 1
	Time	1 for selecting a mode because it is fast, 0 otherwise
		for household, mean value ranging from 0 to 1
	Money	1 for selecting a mode because it is cheap, 0 otherwise
		for household, mean value ranging from 0 to 1
	Metro intention	1 for planning to take metro as primary mode, 0 otherwise
		for household, mean value ranging from 0 to 1
Built environment features	Workplace LUM	Land use mixture within 500 m buffer of work location
		for household, minimum value for household members
	Home LUM	Land use mixture within 500 m buffer of home location
	Workplace population density	Population density within 500 m buffer of work location, in 10^3 people per km^2
		for household, minimum value for household members
	Workplace rail proximity	Distance to the closest metro station from workplace, in km
		for household, maximum value for household members
	Home rail proximity	Distance to the closest metro station from home, in km
	Commute distance	Length of the shortest path from home to workplace, in km
		for household, maximum value for household members

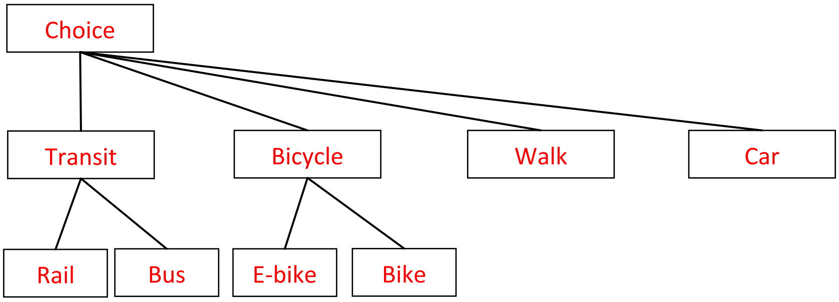

Fig. 3. Structure of the nested logit model.

The choice probability for alternative i for person n, is shown in Eq. (2) (Train, 2003):

$$P_{ni} = \frac{e^{V_{ni}/\lambda_k}\left(\sum_{j\in B_k} e^{V_{nj}/\lambda_k}\right)^{\lambda_k-1}}{\sum_{l=1}^{K}\left(\sum_{j\in B_l} e^{V_{nj}/\lambda_l}\right)^{\lambda_l}} \tag{2}$$

where V_{ni} is the observed utility that person n obtains from alternative i in nest B_k; similarly, V_{nj} is the observed utility that person n obtains from alternative j in nest B_l; λ_k is a measure of the degree of independence in unobserved utility among the alternatives in nest k; and similarly, λ_l is a measure of the degree of independence in unobserved utility among the alternatives in nest l. Each observed utility is a function of a vector of independent variables, which again include socio-economic, attitudinal, and built environment measures but quantified for the individual commuter.

Both the binary logit model and the nested logit model are estimated using the R software. Description of the estimation procedure and software package can be found in Croissant (2012).

4. Results

4.1. Car ownership and modal choice characteristics

The survey data indicates that the three neighborhoods located near metro stations and Jinqiao have similar levels of car ownership. About 33 percent of households in metro-proximate areas of Gongfuxincun, Jiuting, Xinzhuang own one or more cars, compared to 34 percent for Jinqiao, located beyond walking distance from the metro. Therefore, little effect of rail transit proximity on household car purchase decision can be discerned from a simple comparison of these percentages.

The survey data suggests more significant and complex effects of rail transit on the mode choice of suburban residents. As shown in Fig. 4, rail transit is the most popular commuting mode for residents of the three neighborhoods near metro stations, accounting for 40 percent of their commuting trips. In comparison, residents of Jinqiao use rail transit as the primary mode for only 9 percent of their commuting trips. Driving is used for only 20 percent of commutes by residents in the three metro-proximate areas, in comparison to 24 percent for Jinqiao. However, the much higher mode share of rail transit for the three neighborhoods seems to have also come with a substantial reduction in bicycling. Only 5 percent and 13 percent of their commuting trips, respectively, are by bike and E-bike, compared to 11 percent and 18 percent for Jinqiao.

To understand the true impacts of rail transit-supported urban expansion, effects of other relevant factors must be controlled for. Therefore, regression analysis is required.

4.2. Factors explaining car ownership

Descriptive statistics for the independent variables to be included in the regression model for household car ownership are shown in (a) of Table 3. The average number of employees per household is slightly below 2, and 23 percent of them have jobs that tend to have flexible work schedules. The average household has more senior citizens than children, and about 59 percent of the household members are males. Households on average receive a transportation subsidy of ¥130 per month, which is almost 2 percent of their monthly income.

Sampled households on average are located 1.93 km from the nearest metro station. Home rail proximity still has a modest standard deviation mostly due to the inclusion of data for Jinqiao. For households workplaces on average are 2.43 km from the closest metro station, and the average commuting distance is 14.53 km.[3] Note that workplace rail proximity has a large standard deviation, because respondents are working in diverse locations in the metropolitan area, including ones far from any metro station.

Impressively, 68 percent of the households indicate that they intended to commute by the metro when moving to current neighborhood. Among the measured attitudinal factors, saving time (67 percent) is the most common consideration, but saving money (38 percent), being comfortable (28 percent), and being safe (24 percent) are also frequently mentioned concerns.

The estimated binomial logit model of car ownership is shown in Table 4. The main findings are: (1) income is positively associated with car ownership; (2) working as a business owner, enterprise executive, or governmental official, which often has a flexible schedule, is positively related to car ownership; (3) receiving transportation subsidy is also positively associated with owning cars; (4) larger number of children in a household is related with higher likelihood of being a car owner; (5) longer commuting distance is associated with higher level of car ownership, but other built environment factors are not significant predictors; and (6) most attitudinal factors are significant predictors of household car ownership status. Specifically, concerns for time, comfort, and safety positively, whereas concerns for money negatively, relate to car ownership. However, the negative association between the intention to commute by the metro and the status of being a car owner is not statistically significant.

The model fit, as indicated by McFadden R square value of 0.35, is very good. McFadden's R square is a commonly used measure of goodness of fit for maximum likelihood estimation. According to McFadden (1977), the values of this measure tend to be much lower than conventional R square values for OLS; McFadden R square values greater than 0.2 represent excellent goodness of fit.

4.3. Factors explaining commuting mode choice

Table 3(b) displays the descriptive statistics of the independent variables to be employed for the regression analysis of commuting mode choice. These are generally consistent with those under Table 3(a). One difference worth noting is that age is considered a relevant factor in modeling mode choice. Given that the relationship between age and a given

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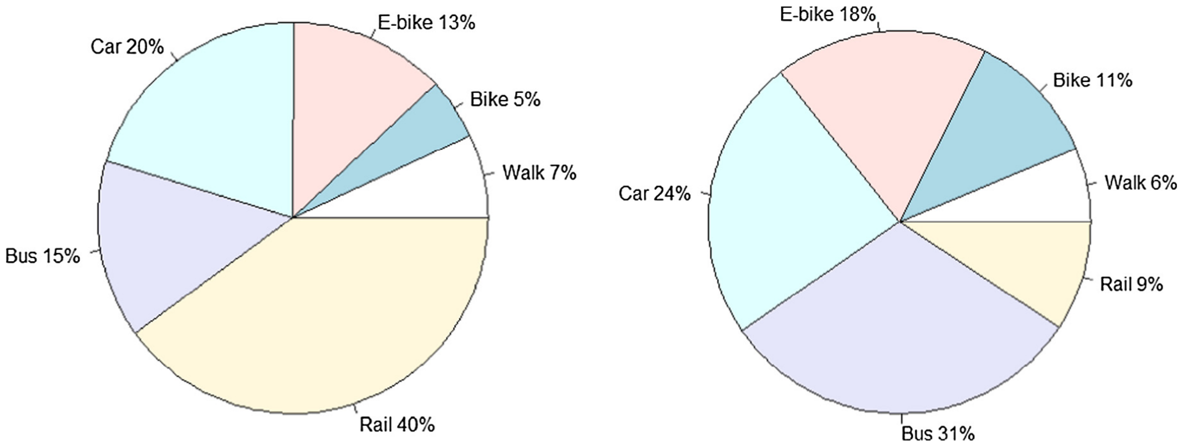
[3] The mean values of workplace rail proximity and commuting distance for households are 2.43 km and 14.53 km respectively, which are significantly larger than the mean values of 1.80 km and 11.15 km for individual commuters. This is because these household mean values are computed on the basis of the maximum individual values for each household.



(a) Three Areas near Metro

(b) Jinqiao Area

Fig. 4. Residents' commuting mode shares.

Table 3
Descriptive statistics of independent variables.

	(a) Household Level Variables, for Car Ownership Model				*(b) Individual Level Variables, for Mode Choice Model*			
	Mean	Sd	Min	Max	Mean	Sd	Min	Max
Age					37.92	10.50	18	76
Age squared					1547.77	862.73	324	5776
Gender	0.59	0.31	0.00	1.00	0.57	0.50	0.00	1.00
# of employees	1.78	0.61	0.00	4.00	1.98	0.61	0.00	4.00
# of children	0.42	0.52	0.00	3.00	0.44	0.52	0.00	3.00
# of seniors	0.86	0.85	0.00	3.00	0.81	0.85	0.00	3.00
Income	82.64	47.97	10.00	290.00	47.30	27.70	0.00	120.00
Employment type	0.24	0.37	0.00	1.00	0.23	0.42	0.00	1.00
Subsidy	0.13	0.28	0.00	2.60	0.07	0.20	0.00	2.20
Safety	0.24	0.37	0.00	1.00	0.25	0.43	0.00	1.00
Comfort	0.28	0.39	0.00	1.00	0.27	0.44	0.00	1.00
Money	0.38	0.43	0.00	1.00	0.39	0.49	0.00	1.00
Time	0.67	0.40	0.00	1.00	0.66	0.47	0.00	1.00
Metro intention	0.68	0.42	0.00	1.00	0.68	0.47	0.00	1.00
Workplace LUM	0.57	0.17	0.00	0.96	0.64	0.17	0.00	0.96
Home LUM	0.64	0.13	0.27	0.96	0.64	0.13	0.27	0.96
Workplace population density	10.53	12.80	0.00	66.94	15.51	16.49	0.00	75.86
Workplace rail proximity	2.43	3.86	0.00	49.62	1.80	3.05	0.00	49.62
Home rail proximity	1.93	1.04	0.29	3.43	1.96	1.04	0.29	3.43
Commute distance	14.53	12.38	0.01	85.80	11.15	10.88	0.01	85.80

transportation mode (for example, driving) tends to change direction after an individual reaches a certain stage of life, the squared value of age is also included in the regression.

The nested logit model uses car as the reference mode. The regression outcomes are reported in Table 5. The results indicate that: (1) income is positively associated with commuting by car; (2) important government and business jobs that tend to have flexible work schedules relate positively to driving to work; (3) transportation subsidy also relates to more driving to work; (4) age has negative relationships with walking and using public transportation until some points, after which the relationships become positive; (5) men are less likely to choose walk, bus, or rail as commuting mode, and having more employees in a household is also negatively associated with commuting by bus or rail; (6) several built environment factors show significant relationships with commuting mode choice; and (7) all attitudinal variables are significantly related to commuting mode choice. The empirical results in connection with built environment and attitudinal variables are particularly rich, and hence are elaborated in the following paragraphs.

The regression outcomes strongly suggest that the built environment influences commuting mode choice. Most directly related to the purpose of this study are the highly significant negative coefficients associated with workplace rail proximity and home rail proximity, which indicate that longer distances to the nearest metro station from both home and workplace are associated with lower probabilities of commuting by rail in comparison to car. Moreover, commuting distance has a

Table 4
Estimated binomial logit model of car ownership (N = 823).

	Estimate	Z-value	Exp(β)
(Intercept)	−3.76***	−4.47	
Gender	0.34	0.91	1.40
# of employees	0.33	1.58	1.38
# of children	0.38**	2.03	1.47
# of seniors	−0.04	−0.30	0.97
Income	0.02***	6.50	1.02
Employment type	1.11***	4.00	3.05
Subsidy	2.05***	4.15	7.79
Safety	0.61**	2.21	1.83
Comfort	1.63***	6.18	5.09
Money	−1.40***	−5.15	0.25
Time	0.57**	2.07	1.77
Metro intention	−0.08	−0.32	0.93
Workplace LUM	−0.20	−0.31	0.82
Home LUM	−0.37	−0.47	0.69
Workplace population density	0.01	0.58	1.01
Workplace rail proximity	0.03	1.13	1.03
Home rail proximity	−0.03	−0.26	0.97
Commute distance	−0.02**	−2.33	0.98

Indicated by estimate with level of significance (* < 0.1, ** < 0.05, *** < 0.01)
Model fit:
Null deviance: 1050.00 on 822 degrees of freedom
Residual deviance: 682.34 on 804 degrees of freedom
McFadden R^2: 0.35

Table 5
Estimated nested logit model of commuting mode choice (N = 1436).

Variable	Walk		Bike		E-Bike		Bus		Rail	
	Estimate	Exp(β)	Estimate	Exp(β)	Estimate	Exp(β)	Estimate	Exp(β)	Estimate	Exp(β)
Intercept	12.32***		3.78		4.26*		7.46***		8.82***	
Age	−0.47***	0.63	−0.17	0.84	−0.18	0.84	−0.28***	0.76	−0.30***	0.74
Age squared	0.01***	1.01	0.00	1.00	0.00*	1.00	0.00***	1.00	0.00***	1.00
Gender	−0.82**	0.44	−0.14	0.87	0.08	1.08	−0.78***	0.46	−0.69***	0.50
# of employees	−0.26	0.77	−0.29	0.75	−0.27	0.76	−0.41**	0.66	−0.54***	0.58
# of children	0.83**	2.29	0.30	1.35	0.56**	1.75	−0.04	0.96	−0.13	0.88
# of seniors	−0.02	0.98	0.18	1.20	0.16	1.17	0.18	1.20	0.14	1.15
Income	−0.06***	0.94	−0.05***	0.95	−0.04***	0.96	−0.03***	0.97	−0.03***	0.97
Employment type	−0.31	0.73	−1.07***	0.34	−0.73**	0.48	−0.86***	0.42	−0.84***	0.43
Subsidy	−6.41***	0.00	−4.78***	0.01	−4.35***	0.01	−3.84***	0.02	−2.60***	0.07
Safety	0.51	1.67	−0.89***	0.41	−1.30***	0.27	−0.04	0.96	0.07	1.07
Comfort	−2.27***	0.10	−2.28***	0.10	−2.18***	0.11	−2.13***	0.12	−1.92***	0.15
Money	2.17***	8.76	2.45***	11.59	2.17***	8.76	1.58***	4.85	1.14***	3.13
Time	−1.97***	0.14	0.46	1.58	0.66**	1.93	−0.73***	0.48	−0.48**	0.62
Metro intention	−0.79**	0.45	−0.31	0.73	−0.20	0.82	0.47*	1.60	0.72***	2.05
Workplace LUM	1.84	6.30	0.50	1.65	0.67	1.95	0.19	1.21	0.53	1.70
Home LUM	−0.73	0.48	2.56**	12.94	1.75*	5.75	1.76**	5.81	0.70	2.01
Workplace population density	−0.09**	0.91	−0.03**	0.97	−0.03***	0.97	0.01	1.01	0.03***	1.03
Workplace rail proximity	0.20*	1.22	0.08	1.08	0.04	1.04	−0.01	0.99	−0.26**	0.77
Home rail proximity	−0.08	0.92	−0.12	0.89	−0.12	0.89	−0.07	0.93	−0.44***	0.64
Commute distance	−0.09***	0.91	−0.03***	0.97	−0.03**	0.97	0.03***	1.03	0.06***	1.06
Inclusive utility	0.37**									
Significance levels	Indicated by estimate with level of significance (* < 0.1, ** < 0.05, *** < 0.01)									
Model fit	Log-likelihood: −1464.00 McFadden R^2: 0.40 Likelihood ratio test : chisq = 1923.7 (P value = 0.00)									

highly significant positive relationship with choosing the metro as primary commuting mode, suggesting that rail transit has a clear competitive edge over car for long commutes. Additionally, population density in job location also relates positively to choosing the metro over car for commuting.

The regression results also clearly indicate that the attitudinal variables are significant predictors of commuting mode choice. Concern for money relates positively to commuting by rail transit, whereas desires for time savings and comfort

Table 6
Estimated nested logit model of commuting mode choice for car owners (N = 511).

Variable	Walk		Bike		E-Bike		Bus		Rail	
	Estimate	Exp(β)	Estimate	Exp(β)	Estimate	Exp(β)	Estimate	Exp(β)	Estimate	Exp(β)
Intercept	1.89		−1.76		0.63		5.55		8.79**	
Age	−0.30	0.74	−0.17	0.84	−0.19	0.83	−0.33.	0.72	−0.36*	0.70
Age squared	0.01	1.01	0.00	1.00	0.00	1.00	0.00**	1.00	0.00*	1.00
Gender	−3.00	0.05	−1.13	0.32	−1.07*	0.34	−2.46***	0.09	−1.93***	0.15
# of employees	0.95	2.59	0.76	2.14	0.15	1.16	0.48	1.62	−0.14	0.87
# of children	1.50	4.48	0.46	1.58	0.58	1.79	−0.41	0.66	0.15	1.16
# of seniors	0.76	2.14	0.49	1.63	0.18	1.20	0.38*	1.46	0.19	1.21
Income	−0.02	0.98	−0.04*	0.96	−0.03**	0.97	−0.01*	0.99	−0.02**	0.98
Employment type	−1.69	0.18	−1.90	0.15	−1.10	0.33	−0.72	0.49	−0.69	0.50
Subsidy	−3.23	0.04	−3.40	0.03	−2.04	0.13	−3.28**	0.04	−2.74**	0.06
Safety	0.34	1.40	−0.73	0.48	−1.04	0.35	0.06	1.06	−0.20	0.82
Comfort										
Money	2.74*	15.49	3.22***	25.03	2.99***	19.89	1.92***	6.82	1.80***	6.05
Time	−3.09*	0.05	1.16	3.19	0.45	1.57	−1.69***	0.18	−0.76*	0.47
Metro intention	−0.98	0.38	0.33	1.39	0.42	1.52	0.68	1.97	1.10**	3.00
Workplace LUM	−0.09	0.91	−0.75	0.47	0.98	2.66	−0.18	0.84	−0.82	0.44
Home LUM	−0.42	0.66	4.21	67.36	1.23	3.42	0.50	1.65	−0.27	0.76
Workplace population density	−0.02	0.98	−0.12	0.89	−0.05	0.95	0.01	1.01	0.03**	1.03
Workplace rail proximity	0.31	1.36	−0.03	0.97	−0.02	0.98	0.05	1.05	−0.76**	0.47
Home rail proximity	0.75	2.12	−0.24	0.79	−0.29	0.75	−0.11	0.90	−0.78***	0.46
Commute distance	−0.48**	0.62	−0.02	0.98	−0.06	0.94	0.02	1.02	0.06***	1.06
Inclusive utility	0.49**									
Significance levels	Indicated by estimate with level of significance ($*$ < 0.1, $**$ < 0.05, $***$ < 0.01)									
Model fit	Log-likelihood: −358.65 McFadden R^2: 0.46 Likelihood ratio test : chisq = 616.71 (P value = 0.00)									

relate positively to commuting by car; concern for safety is associated with lower mode shares for bike and e-bike. Further, intention to use the metro shows a highly significant positive connection to its actual use as primary commuting mode.

The inclusive utility modeled is highly significant, indicating that the specified nest structure is appropriate to address the IIA issue. The McFadden R^2 is 0.40, which shows that the model performs very well in explaining individuals' commuting mode choice.

4.4. Commuting mode choice by car owners

There is a likely endogenous relationship between car ownership and commuting mode choice, and therefore regression analysis of people's commuting mode choice without simultaneously considering their car ownership status may result in biased estimation. To address this concern, we estimate another nested logit model of commuting mode choice using only the subsample of employees from households that own one or more cars. The outcomes of the third model are presented in Table 6. The results are mostly consistent with those of the model estimated using the whole sample, which suggests that endogeneity between car ownership and mode choice does not significantly bias the estimation. However, there are some noticeable differences, and the most obvious difference is that comfort is no longer included as an explanatory variable. This is because among commuters from car-owning households, none of those who consider comfort as a major concern chooses walk as primary mode for journey to work, and thus inclusion of comfort as an independent variable in the nested logit model would cause the singularity problem in estimation.[4]

Another important difference is that several coefficients, including those for gender, money, time, metro intention, workplace rail proximity, and home rail proximity, are considerably larger in absolute value. This suggests that the effects of gender, attitudes, and home and workplace proximities to metro station become more pronounced on car owners' choice of rail, instead of driving, as primary commuting mode.

4.5. Substitutions between rail, bus and car

In light of the unresolved major controversy between rail transit supporters and detractors regarding the extent to which rail substitutes pre-existing bus ridership, we used the estimated model to explore the substitutions between rail, bus and car. We predict the mode shares for the four suburban neighborhoods under the hypothetical scenario in which the rail

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[4] To test the robustness of the regression results, we also estimated a multinomial model that included comfort as an independent variable. The results are also highly consistent.

service is outside the range of direct walking and biking access. Specifically, we assumed that all survey respondents' home and work locations were at least 5 km away from the nearest metro station, and calculated the mode shares.

Not surprisingly, the predicted mode share for rail would drop from 25 percent to almost 0 percent, whereas the predicted shares for bus and car would both increase quite significantly. The largest increase would be for bus, at 14 percent, which indicates that bus and rail are indeed closest substitutes. Thus, our analysis shows that former bus passengers constitute about 60 percent of rail transit ridership, somewhat lower than the percentages cited by Lave (1998). On the other hand, without access to rail service the mode share for car would increase 7 percent, indicating that the rail transit has been reasonably effective in reducing automobile dependence in Shanghai's new suburbs.

5. Limitations

Because the research employed spatial cluster sampling for the household travel surveys, the observations are from only four neighborhoods, which do not have much variation in the built environment. This may have contributed to the lack of statistically significant association between home built environment characteristics and car ownership in the estimated regression model. For future research, if available resources permit, it will be highly desirable to include in the sample a larger number of suburban neighborhoods with more diverse built environment profiles.

A related limitation, which may also have contributed to the lack of statistically significant relationship between the built environment and car ownership, is that some potentially relevant control variables are missing. In particular, data on parking availability is not available for this research, even though variation in parking supply may complicate the empirical result regarding the relationship between car ownership and station proximity. For example, if new apartments built near rail transit stations are designed with good parking spaces to attract high-income households, the relatively strong appeal of convenient parking may offset any effect of station proximity on car ownership.

A third shortcoming of this research is that it focuses primarily on rail transit versus car as alternative transportation modes, while treating other modes in a peripheral manner. A possible substitution effect of rail transit on bicycling, which is strongly suggested by the differences in mode shares between Jinqiao and the other three study areas, needs to be rigorously assessed. Future research should aim to more systematically examine the complex relationships among all the choice alternatives. However, it is important to understand that, even if rail transit replaces part of bicycling, the overall outcome can still be highly positive due to the increased spatial accessibility and likely improvement in transportation safety.

6. Conclusions

Results of this empirical examination of household car ownership and individual commuting mode choice in selected Shanghai suburban neighborhoods strongly suggest that the rail transit-supported urban growth generates significant positive effects. The effects are seen only in residents' commuting mode choice, not in their car ownership status. A fundamentally encouraging finding is that rail transit is chosen by a high percentage of residents who live in proximity to a metro station as primary commuting mode. In the case of the three metro station-proximate areas, the mode share for rail transit is 40 percent, much higher than the 9 percent for Jinqiao area, which was beyond walking distance from any metro station when the travel survey was conducted. The 40 percent share for rail transit is also significantly higher than the overall mode share for rail in Shanghai.[5]

Perhaps even more revealing of positive impacts of the rail transit is the finding that longer-distance commuting gives the metro a clear competitive edge over the car. Providing a viable public transportation option for the suburbanizing population, who typically have a long journey to work, is the key objective of rail transit development in large Chinese cities. As the metro system captures a large mode share for long commutes, the rail transit-supported urban expansion effectively moderates automobile dependence that would otherwise reach a much higher level.

Our empirical study has also identified various socio-economic, built environment, and attitudinal variables that help explain people's car ownership status and mode choice. Socioeconomic factors are the most important predictors of car ownership and use. Higher income, higher job position with a flexible work schedule, and larger amount of transportation subsidy all relate significantly to greater probabilities of owning and driving cars. Several built environment variables show significant associations with individuals' choice among alterative commuting modes, although they do not seem to influence households' decision on car purchase. In particular, higher population density in work location and shorter distances to metro stations from home and workplace are strongly associated with higher likelihood of commuting by rail transit. Equally worth paying attention to are the significant associations between people's attitudes and the observed behaviors. Considerations of money, time, comfort, and safety appear to exert measurable influences on car ownership and mode choice in the expected directions, and the intention to ride the metro for commuting is reflected in its actual use as primary mode for journey to work.

These empirical findings have important implications for transportation policy and urban planning in Shanghai, in other large Chinese cities, and perhaps in major cities in other developing countries. First, rail transit-supported urban growth can

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[5] Rail transit accounted for 17 percent of Shanghai commuters' trips in 2009. Although data is not available for 2010 or 2011, it is without reasonable doubt that commuting mode share for rail for the city as whole was far below 40 percent.

be an effective strategy for countering automobile dependence typically associated with the population increase, economic development, and physical expansion of large cities. The outcomes, especially the reduced mode share for car, seem to justify the widely-spread enthusiasm among Chinese transportation planners and policy makers for this strategy.

Secondly, this strategic approach must be facilitated by both transportation policies and land use plans. In particular, transportation subsidy generally encourages car use and therefore should be carefully redesigned, whereas urban land use should be integrated with rail transit development by locating new residential neighborhoods and commercial and service establishments near metro stations, and by increasing development densities. Future practice of transit-oriented development (TOD) in large Chinese cities must be adapted to the local context, which is partly characterized by rail network layout and station locations, to help maximize the benefits created by modern rail transit service.

Thirdly, in light of the strong connection between people's attitudes and travel behaviors, rail transit-supported urban expansion can be complemented by ensuring timely provision of rail transit for people who are relocating to the suburbs. Moreover, greater effectiveness can be achieved by improving the speed, safety, and comfort of rail transit service.

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References

Bamberg, S., 2006. Is a residential relocation a good opportunity to change people's travel behavior? Results from a theory-driven intervention study. Environ. Behav. 38 (6), 820–840.

Baum-Snow, Nathaniel, Kahn, Matthew E., 2005. The effects of urban rail transit expansions: evidence from sixteen cities from 1970 to 2000. In: Burtless, Gary, Pack, Janet Rothenberg (Eds.), Brookings-Wharton Conference on Urban Affairs.

Bergman, Å., Gliebe, J., Strathman, J., 2011. Modeling access mode choice for inter-suburban commuter rail. J. Public Transport. 14 (4), 23–42.

Bhat, C.R., Guo, J.Y., 2007. A comprehensive analysis of built environment characteristics on household residential choice and auto ownership levels. Transport. Res. Part B: Methodol. 41 (5), 506–526.

Cao, X., 2009. Disentangling the influence of neighborhood type and self-selection on driving behavior: an application of sample selection model. Transportation 36 (2), 207–222.

Cervero, R., Day, J., 2008. Suburbanization and transit-oriented development in China. Transp. Policy 15 (5), 315–323.

Chen, C., Gong, H., Paaswell, R., 2008. Role of the built environment on mode choice decisions: additional evidence on the impact of density. Transportation 35 (3), 285–299.

China Bureau of Statistics, 2014. China Statistical Year Book. <http://www.stats.gov.cn/tjsj/ndsj/>.

China Bureau of Statistics, 2011. Bulletin on the 2010 National Population Census Key Data (in Chinese).

ChinaNews, 2015. In 2030 China will Have Over 300 Million Migrant Population and About 70 Percent of Its People Urbanized (in Chinese). <http://www.chinanews.com/life/2015/07-10/7397661.shtml>.

Creemers, L., Cools, M., Tormans, H., Lateur, P.-J., Janssens, D., Wets, G., 2012. Identifying the determinants of light rail mode choice for medium- and long-distance trips: results from a stated preference study. Transport. Res. Rec.: J. Transport. Res. Board 2275, 30–38.

Creemers, L., Tormans, H., Bellemans, T., Janssens, D., Wets, G., Cools, M., 2015. Knowledge of the concept light rail transit: exploring its relevance and identification of the determinants of various knowledge levels. Transport. Res. Part A: Policy Pract. 74, 31–43.

Croissant, Yves, 2012. Estimation of Multinomial Logit Models in R: The mlogit Packages. <ftp://193.1.193.75/disk1/cran.r-project.org/web/packages/mlogit/vignettes/mlogit.pdf>.

Dargay, J., Gately, D., Sommer, M., 2007. Vehicle ownership and income growth, worldwide: 1960–2030. Energy J., 143–170

De Vos, J., Derudder, B., Van Acker, V., Witlox, F., 2012. Reducing car use: changing attitudes or relocating? The influence of residential dissonance on travel behavior. J. Transport Geogr. 22, 1–9.

EastDay.com, 2015. Next 15 Years China will have 230 Million People Migrating to Cities (in Chinese). <http://finance.eastday.com/m/20150710/u1a8788332.html>.

Ewing, R., Cervero, R., 2010. Travel and the built environment. J. Am. Plann. Assoc. 76 (3), 265–294.

Forsey, D., Habib, K.N., Miller, E.J., Shalaby, A., 2013. Evaluating the impacts of a new transit system on commuting mode choice using a GEV model estimated to revealed preference data: a case study of the VIVA system in York Region, Ontario. Transport. Res. Part A: Policy Pract. 50, 1–14.

Gakenheimer, R., 1995. Motorization in China Discussion Paper. Department of Urban Studies and Planning, MIT.

Handy, S., Cao, X., Mokhtarian, P., 2005. Correlation or causality between the built environment and travel behavior? Evidence from Northern California. Transport. Res. Part D 10, 427–444.

Hass-Klau, C., Crampton G., Benjari, R., 2004. Economic Impact of Light Rail: The Results of 15 Urban Areas in France, Germany, UK and North America. Environmental & Transport Planning.

Hess, D.B., Ong, P.M., 2002. Traditional neighborhoods and automobile ownership. Transport. Res. Rec.: J. Transport. Res. Board 1805 (1), 35–44.

Hong, J., Shen, Q., Zhang, L., 2014. How do built-environment factors affect travel behavior? A spatial analysis at different geographic scales. Transportation 41 (3), 419–440.

Kain, John F., 1999. The urban transportation problem: a reexamination and update. In: Gómez-Ibánez, Jose A., Tye, William B., Winston, Clifford (Eds.), Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer. The Brookings Institution, Washington, D.C..

Kain, John F., Liu, Z., 1999. Secrets of success: assessing the large increases in transit ridership achieved by Houston and San Diego. Transport. Res. Part A 33, 601–624.

Kwoka, G.J., Boschmann, E.E., Goetz, A.R., 2015. The impact of transit station areas on the travel behaviors of workers in Denver, Colorado. Transport. Res. Part A: Policy Pract. 80, 277–287.

Lave, C., 1998. 25 years of U.S. energy policy successes, failures, and some general lessons for public policy. Transport. Quart. 52 (4), 7–13.

Li, J., Walker, J.L., Srinivasan, S., Anderson, W.P., 2010. Modeling private car ownership in China. Transport. Res. Rec.: J. Transport. Res. Board 2193 (1), 76–84.

Limtanakool, N., Dijst, M., Schwanen, T., 2006. The influence of socioeconomic characteristics, land use and travel time considerations on mode choice for medium- and longer-distance trips. J. Transp. Geogr. 14 (5), 327–341.

Lindsey, M., Schofer, J.L., Durango-Cohen, P., Gray, K.A., 2010. Relationship between proximity to transit and ridership for journey-to-work trips in Chicago. Transport. Res. Part A: Policy Pract. 44 (9), 697–709.

Litman, T., 2007. Evaluating Rail Transit Criticism. Victoria Transport Policy Institute.

Luan, X., Lin, X., McGuinness, E., Yang, J., 2014. Emerging public-private partnerships in china's rail mass transit. Transport. Res. Rec.: J. Transport. Res. Board 2450, 127–135.

McFadden, D., 1977. Quantitative Methods for Analyzing Travel Behavior of Individuals: Some Recent Developments. Institute of Transportation Studies, University of California.

Meyer, John R., Kain, John F., Wohl, Martin, 1965. The Urban Transportation Problem. Harvard University Press, Cambridge, MA.

Mokhtarian, P.L., Cao, X., 2008. Examining the impacts of residential self-selection on travel behavior: a focus on methodologies. Transport. Res. Part B: Methodol. 42 (3), 204–228.

Nelson, P., Baglino, A., Harrington, W., Safirova, E., Lipman, A., 2007. Transit in Washington, DC: current benefits and optimal level of provision. J. Urban Econ. 62 (2), 231–251.

Nolan, A., 2010. A dynamic analysis of household car ownership. Transport. Res. Part A: Policy Pract. 44 (6), 446–455.

Olaru, D., Smith, B., Taplin, J.H.E., 2011. Residential location and transit-oriented development in a new rail corridor. Transport. Res. Part A: Policy Pract. 45 (3), 219–237.

Pan, H., Shen, Q., Liu, C., 2011. Transit-oriented development at the urban periphery: insights from a case study in Shanghai, China. Transport. Res. Rec.: J. Transport. Res. Board 2245, 95–102.

Pan, H., Zhang, M., 2008. Rail transit impacts on land use: evidence from Shanghai, China. Transport. Res. Rec.: J. Transport. Res. Board 2048, 16–25.

Potoglou, D., Kanaroglou, P.S., 2008. Modelling car ownership in urban areas: a case study of Hamilton, Canada. J. Transp. Geogr. 16 (1), 42–54.

Prillwitz, J., Harms, S., Lanzendorf, M., 2006. Impact of life-course events on car ownership. Transport. Res. Rec.: J. Transport. Res. Board 1985 (1), 71–77.

Scheiner, J., Holz-Rau, C., 2012. Changes in travel mode use after residential relocation: a contribution to mobility biographies. Transportation, 1–28.

Schimek, P., 1996. Household motor vehicle ownership and use: how much does residential density matter? Transport. Res. Rec.: J. Transport. Res. Board 1552, 120–125.

Senbil, M., Kitamura, R., Mohamad, J., 2009. Residential location, vehicle ownership and travel in Asia: a comparative analysis of Kei-Han-Shin and Kuala Lumpur metropolitan areas. Transportation 36 (3), 325–350.

Shanghai Municipal Government, 2015. Report on the 5th Comprehensive Transportation Survey in Shanghai.

Shen, Q., 1997. Urban transportation in Shanghai, China: problems and planning implications. Int. J. Urban Reg. Res. 21 (4), 589–606.

Shiftan, Y., Barlach, Y., 2002. Effect of employment site characteristics on commute mode choice. Transport. Res. Rec.: J. Transport. Res. Board 1781 (1), 19–25.

Small, K., Verhoef, E., 2007. The Economics of Urban Transportation. Routledge, New York.

Train, K., 2003. Discrete Choice Methods With Simulation. Cambridge University Press.

Van Acker, V., Witlox, F., 2010. Car ownership as a mediating variable in car travel behaviour research using a structural equation modelling approach to identify its dual relationship. J. Transport Geogr. 18 (1), 65–74.

Voith, Richard. 2005. Comments on Baum-Snow, Nathaniel and Matthew E. Kahn. 2005. The Effects of Urban Rail Expansion: Evidence from Sixteen Cities from 1970 to 2000, Brookings-Wharton Conference on Urban Affairs 2005, Volume edited by Gary Burtless and Janet Rothenberg Pack.

Winston, C., Maheshri, V., 2007. On the social desirability of urban rail transit systems. J. Urban Econ. 62 (2), 362–382.

Yang, J., Shen, Q., Shen, J., He, C., 2012. Transport impacts of clustered development in Beijing: compact development versus overconcentration. Urban Stud. 49 (6), 1315–1331.

Zaretsky, Adam M., 1994. Riding the rails: a look at light rail. The Regional Economist. Federal Reserve Bank of St. Louis, October.

Zhao, P., 2010. Sustainable urban expansion and transportation in a growing megacity: consequences of urban sprawl for mobility on the urban fringe of Beijing. Habitat Int. 34 (2), 236–243.

Zhou, Yixing, Meng, Cunyan, 1998. The tendency of suburbanization of big cities in China. Urban Plan. Rev. 3, 004.