Does Better Subway Accessibility Discourage Driving?

An Analysis Based on 2009 Micro Survey in Beijing

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Abstract *Beijing is investing heavily in urban rail construction, but whether it can effectively reduce congestion and related air pollution is still an open question. An empirical challenge for testing this is the fact that residential location choice and transportation choice are jointly made by a household. Using the micro data from a unique survey conducted in Beijing in 2009, we take advantage of the fanggai housing with pre-determined residential locations to address this endogeneity. Heckman two-stage regression technique is also employed to control for possible self selection bias. We find that better subway accessibility reduces a typical resident's probability of owning a car but does not affect the subsequent mileage driven. Such findings hold for the fanggai housing sample with endogenous residential location. Therefore, the development of urban rail in Beijing does discourage driving through reducing auto ownership and thus has positive congestion-mitigating and environmental consequences.*

Keywords-subway accessibility, car ownership, fanggai housing

I. INTRODUCTION

Decades of rapid economic growth and urbanization dramatically changed China's urban transportation. Unlike before, urban residents are not only traveling longer distances, but also making more trips and relying more on modes using fossil fuels. Rapid motorization has led to a series of problems including air pollution, oil price hikes, congestion, and growing greenhouse gas emissions. Numerous Chinese cities are on the list of the World Health Organization's most polluted cities on earth. Many attribute the oil price surge since 2007 to China's exploding appetite for oil. Peak-hour speeds on urban arterials and expressways often drop below 15 or even 10 kilometers (km) per hour in large cities. In 2006, China overtook the United States as the world's leading emitter of carbon dioxide. Three years later, China became the world's largest market of new vehicles, when China was considered to have just reached the income threshold of accelerated growth in automobile ownership (Dargay et al 2007; Haddock and Jullens 2009).

Beijing, China's capital and one of its most motorized cities, has experienced an average annual increase rate of 12.8% in the number of motor vehicles, which is approaching five million. In five years, such a rapid motorization would lead to an average road speed below 15 km per hour. In 2008, more than 50% of Beijing's air pollutants were from the burning of fossil fuel, mainly consumed by motor vehicles. Along with many other cities, Beijing has been heavily investing in public transit systems. By 2015, Beijing will have 19 urban rail (subway) lines in operation, with a total route length of 561 km. There seems little doubt that the new urban rail lines will be filled with passengers, especially those who do not own cars, the majority of Beijing's residents. However, it is unclear how the development of urban rail will affect the increase in ownership and driving among the urban residents because, on one hand, access to rail transit provides a competing alternative to driving, but on the other hand, the fact that rail transit may reduce surface road congestion (e.g., fewer buses are needed on the same route) can induce more driving from those who can afford to driving.

In this study we use a 2009 micro household survey in Beijing to examine the impact of subway accessibility on urban residents' car ownership and their gasoline consumption.

An empirical challenge the studies like ours face is the fact that residential location choice and transportation choice are jointly made by a household. We use the *fanggai* housing, a legacy from the socialist welfare housing system with pre-determined locations, to address endogeneity in residential location. Our Heckman two-stage regressions show that better subway accessibility reduces a typical resident's probability of owning a car but does not affect the overall mileage driven. Such findings hold for the *fanggai* housing sample which is less subject to endogenous residential location. Overall, we find that the development of urban rail in Beijing does reduce driving through reducing auto ownership and thus has positive congestion-mitigating and environmental consequences.

The next section provides a brief literature review. Section 3 describes the institutional background of *fanggai* housing. Sections 4 and 5 describe the micro survey data and the methodology. Section 6 presents our empirical results, followed by a concluding section.

II. LITERATURE REVIEW

Many factors influence motor vehicle ownership and travel behavior in cities. Economists have been primarily focusing on the effects of income, price, and infrastructure. Income has been considered as a major determinant of motorization. Income elasticities of motor vehicle ownership and use have been studied in many countries and cities, most of which in the industrialized world. Many studies indicate that motorization increases rapidly with income, although the elasticities vary. Ingram and Liu (1999) summarize studies since mid-1960s and find that long-run income elasticities (typically from cross-sectional data) of car ownership are greater than 1.0, while short-run elasticities (typically from time series data) are less than 1.0; income elasticities from urban-level data are similar to or smaller than those from country-level data largely due to the existence of competing modes of transportation; income elasticities of motor vehicle use are less than unity, indicating that motor vehicle use increases less rapidly than ownership.

Vehicle and fuel prices are also important determinants of motorization. Many studies focus on the effects of gasoline price. Compared to the somewhat weak evidence on gasoline price's effect on vehicle ownership, studies generally confirm that increase in gasoline price negatively affect vehicle usage but positively affect the average fuel efficiency of the vehicle stock, although evidence shows that income elasticities are greater than price elasticities in absolute terms for both motor vehicle ownership and use (Ingram and Liu 1999). Last but not least, road infrastructure at the national and city level, usually provided publically is widely recognized to be closely linked to motorization. However, due to the complex relationship between road provision, infrastructure investment decisions made by governments, income and population growth, there seems to be little clear quantitative evidence on how motorization is influenced by road provision.

Planning and transportation researchers, on the other hand, focus more on land use and built environment's effects on motorization and a broader set of travel behaviors, primarily due to the interest in using a better planned built environment to reduce dependence on driving, traffic congestion, and related environmental and health impacts (e.g., climate change, energy shortage, air pollution, and lack of physical activity).There have been several reviews of this literature, such as Crane (2000), Ewing and Cervero (2001), Stead and Marshall (2001), Handy (2005), Guo and Chen (2007), Mokhtarian and Cao (2008), and Ewing and Cervero (2010). Most studies have shown that features of the built environment, such as the "three Ds" (density, diversity or land use mix, and design related to comfort, safety or interest) and street pattern (or connectivity), are often associated with travel behaviors including trip frequency, trip distance, mode choice, etc. However, more and better empirical evidence is needed in order to advance our understanding of the effects of land use on travel and/or health for at least two reasons. First, while a good number of studies have been conducted on urban land use, passenger travel and health/environmental effects, the vast majority of existing evidence is based on cross-sectional data and only confirms the correlations between land use patterns and travel/health, leaving causality unexplained or falsely claimed, as in most studies reviewed in the meta-analysis of Brownson et al (2009) and Ewing and Cevero (2010). Although a small number of studies utilize a range of sophisticated statistical strategies to address the residential sorting and/or omitted variable biases (people's tendency to locate in areas consistent with their housing and travel preferences), most of their results are still suggestive (Guo& Chen, 2007, Mokhtarian & Cao, 2008) and do not seem to be very consistent with each other (TRB 2009, Guo 2009).

Second, almost all major empirical studies are from industrialized countries, where travel behavior, health background and the speed of land use change are completely different from those of developing countries, where air pollution and carbon emissions grow as rapidly as urbanization and motorization. Data and analyses are very much needed to enrich our knowledge in the developing country setting, where on one hand, walking, cycling and transit use are much more important in comparison to the highly motorized countries, while on the other hand, significant and rapid socio-economic changes, including urbanization and motorization, in developing cities provide researchers with significant local built environment variations in time series data.

Zhang (2004) confirms the association between land use density and travel mode choice, controlling for travel time and monetary costs in Hong Kong. In Beijing, Huo et al (2010) find auto ownership increased with commute distance. Zheng et al (2010) also find auto ownership decreased for households with better access to urban public services. Cervero et al (2009) find that in Bogota, whereas road facility designs, like street density, connectivity, and proximity to Cicloviacutea lanes, are associated with physical activity, other attributes of the built environment, like density and land-use mixtures, are not. Zegras (2010) suggests that income dominates the household vehicle ownership decision, although there is also a correlations between several built environment characteristics and a household's likelihood of car ownership. In addition, this study also suggests a range of different design and relative location characteristics display a relatively strong association with VKT, but overall income plays the overall largest single role in determining VKT. Unfortunately, none of these studies were able to infer any true causality between the built environment and travel behavior and/or health, due to the potential self-selection bias. Overall, most planning/urban studies emphasize the effect of land use patterns. Access to transit service is usually used as an optional control variable, the result coefficients of which can by no means be seen as indicating causal relationship. Compared to the spatial pattern of land use and the built environment, little serious attention has been paid to the functional aspects of the built environment (sometimes called community resources), such as the accessibility to transit or other services.

III. FANGGAI HOUSING

In this paper we take advantage of the exogenous location of *fanggai* housing to test the causality from subway accessibility to car ownership and driving choices. Here we briefly introduce the institutional background of *fanggai* housing.

Chinese cities have a complicated housing stock. The homeownership rate is high, about 82%. However, only about half of the owner-occupied housing units are commodity housing units traded in the free market. Most of the rest is *fanggai* housing (or "privatized work-unit housing") resulted from the socialist welfare housing regime.

China implemented its urban housing reform during 1990s. Before the reform, housing was not a commodity and was provided by work unit (*Danwei*) to their employees as employee welfare. Under the centralized planning system, urban land was allocated to work units. A work unit typically used part of its land to construct housing units (work-unit housing)and allocated them to its employees, with the rules based on office ranking, occupational status, working experience etc (Fu et al. 2000). Employees only needed to pay a low rent. As a result, most of urban workers did not need to choose their residential locations.

The housing reform (*fanggai*) was launched in early 1990s. On one hand, housing market has been gradually established. Real estate developers began to construct and sell commodity housing to homebuyers at market price. Homebuyers can choose their residential locations and housing units they preferred freely on the market, subject to their budget constraints and other considerations such as transportation choices. On the other hand, work units were ordered to stop building housing for their workers. Existing employer-owned housing units were privatized by selling to sitting tenants at very low subsidized prices. Such privatized work-unit housing is called *fanggai* housing. Although work units transferred such housing units' ownership to their workers, resale or lease of such housing units to other people outside the original work units who previously owned such units have often been constrained .This means that most of the *fanggai* housing residents are original work unit employees. Under this unique institutional arrangement, the locations of *fanggai* housing owners can be regarded as exogenous.

IV. DATA

This research adopts a unique micro dataset of 826 Beijing households living in 38 residential complexes .It is derived from the "Housing, Transportation and Energy Consumption Survey of Beijing Households", conducted by the Institute of Real Estate Studies at Tsinghua University in September 2009. The dataset covers all key demographic, income, residential location and travel information of each household and its head. We geo-coded the survey micro data and subway lines/stops using a Geographic Information System map of Beijing. The spatial straight-line distance from a household's residential location to the closest subway stop is defined as this household's subway accessibility.

Beijing is a typical monocentric city. The Tiananmen square and nearby *Jianguomenwai* area are conventionally regarded as the city center. Five ring roads (No. 2 to No. 6) have been built from the city center outward (depicted in Fig. 1 as five bold black circles). Most of Beijing' urbanized area is within the No. 5 ring road, with a small amount expanding beyond the No. 5 ring road to the north and east.

Fig. 1 shows the spatial distribution of the 38 complexes in Beijing. 491 household observations are located inside of the 5th ring of Beijing, and 335 observations are located outside of the 5th ring. As for housing property types, 373 households own *fanggai* housing units, accounting for 45 percents of the total. The other households own commodity housing units (including affordable units subsidized by the government).

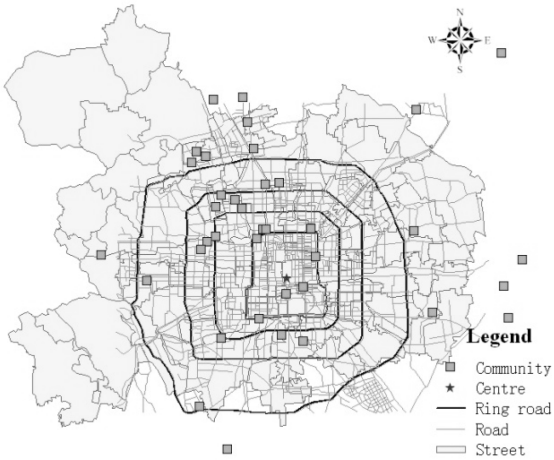

Figure 1. The spatial distribution of the 38 residential complexes.

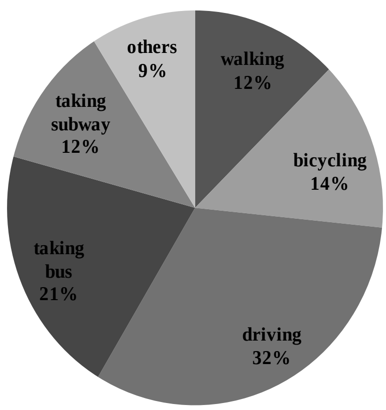

Figure 2. Distribution of commute modes in our sample.

The car ownership rate in our sample is 48%. As shown in Fig. 2, there are six commute modes: walking, bicycling, driving, taking bus, taking subway and others. 32% of the correspondents drive to work, with the average one-way commuting time of 33 minutes. As for the non-motorized modes, 12.6% of the sampled residents commute by foot, with the average one-way commuting time of 11 minutes; 14% commute by bicycling who spend 20 minutes on road one-way. 20.6% of the correspondents commute by bus and their average one-way commuting time is 49 minutes. Only 11.8% take subway to their jobs, and they have the longest one-way commuting time of 57 minutes. This small share of subway usage may be due to the supply shortage of subway lines in Beijing, there were only 5 lines in 2009 with more lines under construction. The long commuting time by subway indicates that the workers who live far away from their jobs are more likely to travel by subway.

V. METHODOLOGY

Our purpose is to test that, controlling for other factors, are those who live closer to subway stops are less likely to own automobile(s) (Equation (1)), and subsequently, can better subway accessibility make people drive less?(Equation (2)). We first analyze the two equations separately using a probit model for Equation 1 and OLS for Equation 2. However, since the OLS estimates in the second stage may suffer from selection bias, Heckman two-step regression technique is used to yield unbiased results.

We have two categories of explanatory variables—household and its head's income and demographic indicators, and built environment attributes. The former group includes household income, household head's age. The latter group contains the linear distance to the closest subway stop (D_SUBWAY), which is our main interest, and the linear distance to the city center (D_CBD). For Equation 2 we have a unique variable indicating whether the respondent can get his gas expenditure reimbursed from his employer. This reimbursement dummy can tell us whether driving is sensitive to fuel cost.

Probability of driving = *f*1(household attributes, D_SUBWAY, D_CBD) (1)

Gas consumption = *f*2(household attributes, reimbursement, D_SUBWAY, D_CBD) (2)

Table 1 presents the variable definitions and summary statistics.

We may find that residents who live near subway stops are more likely to travel by subway. But there are two possible explanations for this observed correlation. On one hand, better subway accessibility will encourage residents to switch to rail transit; On the other hand, it may reflect that those residents who prefer subway travel will choose to live close to subway stops. This self-selection problem will result in mixed results of causality (the usual interest of policymakers) and spatial sorting of urban households.

TABLE I. TABLE TYPE STYLES TABLE ONE VARIABLE DEFINITIONS AND SUMMARY STATISTICS (NO. OF OBS. = 826)

Categories	**Variable Name**	**Definition**	**Mean**	**Std. Dev.**
Car ownership	*CAROWN*	Binary: whether owning a car. 1=YES; 0=NO.	0.48	0.50
Household gasoline consumption	*LGAS*	LOG(Household gasoline consumption per month)	1.12	0.77
Household social/economic characteristics	*LINCOME*	LOG(Household annual income, RMB)	11.39	0.77
	HHSIZE	Size of household	3.13	1.10
	AGE	AGE of household head	46.50	13.80
	D_REIM	Binary: whether the consumption on gasoline can be reimbursed or not 1=YES; 0=NO.	0.17	0.38
Urban form	*LD_SUB*	Log(Distance from residence to closest subway stop, in m)	7.51	1.18
	LCBD	Log (Distance from residence to Tiananmen Square (city center), m)	9.30	0.66

The "policy exogeneity" of *fanggai* housing's location can help us to mitigate the endogeneity between residential location choice and commute mode choice. We will run the regressions for the whole sample first, and then for the sub-sample of *fanggai* housing units, to further verify the causality effect from subway accessibility to car driving probability and usage.

VI. RESULTS

Table Two reports the Probit results for the ownership choice equation and OLS results for the gasoline consumption equation, both for the whole sample and for the *fanggai* housing subsample.

Column (1) and (2) are for the whole sample. From Column (1), we see that income elasticity of car ownership is significant at 1% level and its magnitude close to unity, which is in line with the international experiences suggested in our literature review. Larger households are more likely to own a car. Household head's age has a quadratic effect on ownership choice, with those around 36 years old having the highest probability to own cars. Residents living further from the city center are more likely to own cars. The coefficient of distance to the closest subway stop (LD_SUB, in log term) is positive, indicating that all else equal, households living closer to subway stops are less likely to own cars. This effect is significant at 5% level.

TABLE II. REGRESSION RESULTS OF PROBIT AND OLS MODELS

EQUATION	**(1)**	**(2)**	**(3)**	**(4)**
	Full sample		***Fanggai subsample***	
VARIABLES	**CAROWN**	**LGAS**	**CAROWN**	**LGAS**
LINCOME	0.896***	0.202*	1.030***	0.487**
	(11.913)	(2.005)	(7.804)	(3.075)
HHSIZE	0.136***	-0.031	0.074	-0.030
	(2.859)	(-0.796)	(0.759)	(-0.431)
AGE	0.073**	-0.024	0.051	0.065**
	(2.225)	(-1.013)	(0.978)	(2.366)
AGE^2	-0.001**	0.000	-0.000	-0.001*
	(-2.476)	(0.880)	(-0.947)	(-1.941)
LCBD	0.259**	0.171**	0.554***	0.070
	(2.167)	(2.285)	(6.248)	(0.472)
LD_SUB	0.104***	0.032	0.227***	-0.052
	(2.733)	(0.833)	(3.652)	(-0.574)
D_REIM		0.267**		0.007
		(2.167)		(0.032)
Constant	-15.297***	-2.380	-20.151***	-6.314**
	(-9.806)	(-1.396)	(-8.398)	(-2.892)
Observations	825	389	204	104
R-squared		0.088		0.318

Robust t-statistics (OLS) and z-statistics (Probit) in parentheses. (Std. Err. adjusted for 38 clusters)
*** p<0.01, ** p<0.05, * p<0.1

For the gasoline consumption equation, the income elasticity becomes smaller and less significant, and coefficients of household size and age also lose their significance. This indicates that once the correspondent household chooses to own a car, the amount of driving may be less sensitive to income and demographic characteristics. Though the distance to CBD is still significant, subway accessibility has a weak effect on the amount of driving. As expected, those drivers who can get their gas expenditure reimbursed from employers drive significantly more.

Column (3) and (4) are for sample households living in the *fanggai* housing. In Column (3), we see that the income elasticity of car ownership is larger, but household size and household head's age lose their significance. Residents living in the suburban *Fanggai* housing are more likely to purchase a car and this effect is larger and more significant than that in the full sample. The effect of subway accessibility on car ownership choice is still positively significant at 1% level, and the coefficient size is larger and more significant than in the full sample. For the gasoline consumption equation (Column 4), basic findings from the full sample regression still hold, though the quadratic effect of age becomes significant while the reimbursement dummy lost its significance.

TABLE III. REGRESSION RESULTS OF HECKMAN TWO-STEP MODEL

EQUATION	**(1)**	**(2)**	**(3)**	**(4)**
	Full sample		***Fanggai subsample***	
VARIABLES	**1st step CAROWN**	**2nd step LGASC**	**1st step CAROWN**	**2nd step LGASC**
LINCOME	0.901***	0.192	1.030***	0.596**
	(11.757)	(1.011)	(6.041)	(2.527)
HHSIZE	0.134***	-0.033	0.074	-0.018
	(3.001)	(-0.671)	(0.861)	(-0.278)
AGE	0.071***	-0.025	0.051	0.073**
	(2.935)	(-0.899)	(1.135)	(2.198)
AGE^2	-0.001***	0.000	-0.000	-0.001*
	(-3.303)	(0.684)	(-1.024)	(-1.810)
LCBD	0.253***	0.168**	0.554***	0.134
	(3.287)	(2.080)	(2.641)	(0.711)
LD_SUB	0.101**	0.030	0.227**	-0.027
	(2.339)	(0.753)	(2.313)	(-0.348)
D_REIM		0.268***		0.005
		(2.630)		(0.028)
Constant	-15.245***	-2.201	-20.151***	-8.785*
	(-10.932)	(-0.591)	(-6.540)	(-1.658)
lambda	*-0.021 (-0.050)*		*0.244 (0.502)*	
Observations	821	821	204	204

Robust t-statistics (OLS) and z-statistics (Probit) in parentheses. (Std. Err. adjusted for 38 clusters)
*** p<0.01, ** p<0.05, * p<0.1

In Table Three, Heckman two-step regression technique controlling for possible self-selection bias is employed to test the robustness of our findings. Table Three reports the Heckman results both for the full sample and for the *fanggai* housing subsample. We can see that main findings are similar to those in Table Two, though the coefficient size and significance change slightly. Similar to Table Two, coefficients of distance to the closest subway stop (LD_SUB) is significantly positive in both first-step regressions for the full sample and the *fanggai* subsample, but insignificant in the two second-step regressions. Therefore, controlling for self-selection bias, we find that better subway accessibility reduces a typical resident's probability of owning a car but does not affect the overall mileage driven (gasoline consumption).

VII. CONCLUSION

Beijing government is investing heavily in its urban rail systems to further boost its urban economy as well as to mitigate a series of problems incurred by rapid motorization such as congestion and air pollution. In this paper we empirically examine how the development of subway systems in Beijing affects urban residents' car purchase and driving decisions.

Based on a survey of 826 urban households in Beijing in 2009, we estimate how various factors influence car ownership choice for all households and the subsequent gas consumption for car owners. Heckman two-step estimation technique is employed. The elasticity of car ownership is about unity. Those who are able to get their gasoline costs reimbursed from their employers drive more. We find that better accessibility to subway stops does reduce a typical household's probability of owning a car, but its subsequent effect on overall mileage driven is insignificant. This finding is robust after controlling for the possible endogeneity in residential location by using the *fanggai* housing subsample. We therefore conclude that urban rail development in Beijing discourage driving through reducing auto ownership and thus has positive congestion-mitigating and environmental consequences.

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