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The Effect of Owning a Car on Travel Behavior: Evidence from the Beijing License Plate Lottery*

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Abstract

To reduce pervasive problems of traffic congestion and air pollution, many cities in developing countries have considered restricting vehicle ownership. There is no empirical evidence on these programs' efficacy and costs, but other prior work suggests that not having a car increases the cost of commuting and limits the set of job opportunities. However, these prior studies do not address the endogeneity of car ownership. We leverage a unique policy, the Beijing license plate lottery, to estimate the effect of restricting vehicles on distance traveled and commuting time, while addressing the endogeneity of car ownership. We find that adding a car has little impact on total distance traveled or time spent traveling, but a large impact on mode of travel. While reducing car ownership by 20 percent and car travel distance by 10 percent in Beijing, this policy has not added significantly to overall distances traveled or commute times.

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1 Introduction

The rise in vehicle use in developing countries has exacerbated problems of congestion, pollution, and greenhouse gas emissions. Petroleum consumption in non-OECD countries is expected to grow 60 percent between 2010 and 2030; consumption in OECD countries is expected to decline 7 percent (EIA 2015). This will increase the non-OECD share of transportation petroleum consumption from 40 to 55 percent. Wolfram et al. (2012) suggest that rising incomes in developing countries might increase vehicle ownership and petroleum consumption even more than forecasters have suggested, further exacerbating the environmental strains caused by cars.

One approach to addressing these problems that has gained traction is the introduction of policies sharply restricting car ownership and usage. In cities such as Singapore, Beijing, and Shanghai, local governments have limited the growth in car ownership by capping the number of additional vehicles allowed on the roads (Li 2014). Other cities such as Mexico City have restricted vehicle usage by limiting the days a car can be driven (Davis 2008 and Wang et al. 2013).

However, prior work has implied that these policies could have serious welfare costs and harm long-run economic growth.¹ For example, Holzer et al. (1994) study how car usage affects travel behavior and job outcomes in a simultaneous equations search model. They find that car ownership has a major effect on travel behavior, reducing commute times by 15 percent while increasing commute travel distances by 50 percent. Cars substantially improve labor market outcomes, reducing unemployment durations by 11 percent and increasing wages by 12 percent.

Both the growth in car ownership and the rise of policies restricting ownership depend on a central question: how does car ownership affect travel behavior? The manageability of congestion and air pollution depends not only on vehicle ownership rates, but on how those

¹Gautier and Zenou (2010) and Van Acker and Witlox (2010) present models of car ownership and travel choice. In these models, the choice to buy a car is presented as a discrete household decision that affects the cost of commuting to a job.

vehicles are used. Policies that reduce vehicle ownership will be more effective only if they cause people to drive less; their costs depend on how readily people can substitute to other travel modes.

A sizable literature has attempted to estimate the effect of vehicle ownership on vehicle use, but this work has failed to fully address the endogeneity of ownership: there are many characteristics that influence both car ownership and travel behavior. Raphael and Rice (2002) and Ong (2002) attempt to overcome this endogeneity by instrumenting for car ownership using variables such as state-level insurance premiums, gasoline taxes, and population density. These instruments may remove endogeneity concerns at the individual level, but are still open to endogeneity concerns at the level of the locality, since states with households that favor driving may enact favorable policies. A number of studies simultaneously model vehicle ownership and use (e.g., West 2004 and Bento et al. 2009), but these cannot overcome the problem of unobserved confounders.²

Unobserved characteristics are likely to be a particularly salient problem when investigating the relationship between vehicle ownership and travel behavior. For example, because cars are often used for commuting, unobserved job opportunities or preferences over modes of transportation may bias attempts to compare households based on the number of cars they own. Households that do not own vehicles are unlikely to constitute a valid control group for households that do own vehicles.

This study overcomes these endogeneity concerns by leveraging a unique policy: the Beijing vehicle lottery. Since January 2011, any resident who wishes to purchase a car in Beijing must first win a drawing for license plates. Monthly drawings are held, with success rates of under 1 percent per month over the past year.

From a methodological standpoint, the lottery represents a very useful instrumental variable for car ownership: conditional upon entering, winning the lottery is randomly assigned and is

²All of these studies pertain to developed countries and rely on functional form assumptions to address the endogeneity of vehicle ownership. Bento et al. (2009) jointly model a household's vehicle choice and use decisions, allowing unobserved household attributes to be correlated across these decisions, but they do not account for potential correlation between unobserved and observed attributes.

therefore exogenous to all other characteristics of the household. As a result, we can elicit the causal effect of obtaining a car on vehicle use.

We first address the applicability of the instrumental variable (IV) approach. The lottery outcome is a valid instrument if it is uncorrelated with observed and unobserved determinants of travel behavior. While we cannot directly compare unobservable attributes, we expect observable household and individual attributes that cannot be affected by the lottery, such as gender and birth year, to be comparable across lottery winners and losers. Indeed, we confirm that predetermined attributes of lottery winners and losers are statistically indistinguishable. Furthermore, winning the lottery is a strong predictor of car ownership, suggesting that it is a relevant instrument and reducing concerns about weak instruments bias. Losing households compensate by owning slightly more bicycles.

Then, we examine the impact of car ownership on travel behavior using daily travel diaries filled out by household members and a reduced-form model. Specifically, we regress total distance traveled and time spent traveling on the number of household vehicles, using the lottery outcome to instrument for the number of vehicles. We find that vehicle ownership has a modest but not statistically significant positive effect on both total travel distance and total travel time.

We next investigate how each lottery entrant's mode of travel is affected by adding a car, and find that one additional car more than doubles the distance traveled by car. Car owners increase travel distance by car while decreasing travel distances by other modes such as bus or subway on a nearly one-for-one basis. Taken together, our results suggest that the primary effect of additional cars is not to increase total distance traveled, but rather to cause substitution from other modes of travel into cars.

Because the commute to work can affect labor outcomes, we particularly focus on reported trips to work. In contrast to the findings of Holzer et al. (1994), our surprising finding is that car ownership increases commute distance and decreases commute time, but not to large or statistically significant degrees. Instead of affecting total travel distance, obtaining a car reduces bus and subway trips that have roughly the same distance and time as the car trips.

Our work allows us to draw three direct implications. First, we can leverage differences in travel behavior between winners and losers to directly estimate the impact of the lottery system on total congestion in Beijing. We find that vehicle ownership in Beijing has been reduced by 19.8 percent and total vehicle miles traveled by 9.9 percent. These are large decreases and suggest that the Beijing vehicle restriction policy has had substantial positive impacts on pollution, congestion, and greenhouse gas emissions.

Second, our results have a bearing on the welfare cost of restricting vehicle use. In principle, these costs could include increases in commute travel time, decreases in job opportunities, and disutility related to preferences for driving compared with public transportation. However, we find that failing to obtain an additional vehicle does not result in statistically significant decreases on either commute distance traveled or increases in time of travel. In cities like Beijing that have dense public transportation systems and high traffic congestion, much of the welfare costs of vehicle restriction policies have been confined to the disutility of public transportation.

Third, people obtaining cars reduce other travel modes and use their cars intensively. These changes occur across all strata of individuals, suggesting that people prefer the comfort, convenience, and privacy of cars. Even though our analysis shows that households that use cars do not decrease their time of travel or increase distance traveled by a large or statistically significant amount, households exhibit a strong preference for using cars when they are available.

Our findings are complementary to a broader set of work studying the important environmental externalities associated with cars. Wolfram et al. (2012) suggest that vehicle ownership may increase more quickly in developing countries than indicated by current projections, and hence the future growth in fuel consumption and pollution emissions may be understated. However, their analysis does not account for the possibility that average vehicle use varies with total vehicle ownership. We find that doubling the number of household vehicles roughly doubles driving distance. If we extrapolate out of sample, the doubling implies that as ownership increases over time average use per vehicle will not change, and that driving and fuel consump-

tion will increase proportionately with ownership. Our results underscore their conclusion that existing forecasts of fuel consumption in developing countries may be understated.

These conclusions also have important implications for localities considering vehicle restriction policies. Our work suggests that these policies are effective at reducing congestion and fuel consumption, and that the policies have been less costly than previously believed. In cities like Beijing, with well-developed public transportation systems, limiting the expansion of vehicles may not add significantly to transportation distances or commute times.

Finally, we show that winning the lottery and owning a car affects households more broadly than travel behavior. Winning the lottery increases the probability that the household will contain three generations of people (grandparents, parents, and children). A possible explanation for this finding is that car ownership reduces the cost of child or elderly care. On the other hand, both winners and losers have the same number of full-time employed adults. At a minimum, the increase in household size suggests that household structure is endogenous to vehicle ownership, and therefore should not be included as an independent variable in travel behavior analysis without addressing this endogeneity. This finding also suggests that further research should investigate the broader implications of vehicle ownership.

2 Background and Data

In this study, we combine information about whether a member in a household won the car lottery with the travel diaries of members in the household to study how obtaining a car affects travel behavior. This section provides an overview of the lottery system and summarizes the data.

The overview draws many of the institutional details of the lottery from Yang et al. (2014), who describe the background of the lottery and its short-term effects on the number of vehicles in Beijing. Beijing began its license plate lottery in January 2011. Without a Beijing license plate, cars are prohibited from driving within the area encircled by the fifth ring road between

the hours of 7:00 a.m. and 9:00 a.m., and 5:00 p.m. and 8:00 p.m. Those who already had cars were allowed to keep their vehicles and were allowed to retain their license plates when they traded in or upgraded their old cars. However, no household was allowed to add to its number of cars without first winning the lottery.

From its inception, the lottery has sharply reduced new car purchases. Applicants compete for one of 20,000 new license plates to be issued each month. To put this figure in perspective, annual new car sales grew at an average rate of 31 percent between 2001 and 2010 in Beijing, and reached a height of over 76,000 cars per month during 2010. During the first drawing, there were 10 times as many lottery applicants as license plates available, and the ratio of license plates offered in the lottery to the number of applicants has continued to drop as the number of licenses drawn remained constant and the pool of applicants swelled. By mid-2012, the probability of winning the lottery in a given month fell to less than 2 percent, and the success rate fell below 1 percent in 2015.

Despite the difficulty of obtaining a new car in Beijing, not all lottery winners buy vehicles. Because entering the lottery is free and requires only an online website application, many households enter the lottery even if they are not sure that they want to purchase a car. In June 2012, 10.9 percent of individual lottery winners did not purchase a car, and 22.8 percent of corporate lottery winners did not purchase a vehicle. This suggests that winning the lottery increases the number of household vehicles by less than one.

We leverage a large representative survey of the transportation habits of Beijing's residents. This survey is conducted every few years by the Beijing Transportation Research Commission (BTRC), a government agency tasked with understanding and improving Beijing's transportation system. The survey consists of 40,000 households, drawn proportionately to population from each of Beijing's 16 districts. It was conducted between September and November 2014.

The base survey consists of three types of questions. First, it asks about individuals in the household, including their genders, ages, and relationships with the head of household. Second, it asks about the household and its vehicles. These questions include the square footage

of the home, the household's income category, and the numbers and types of vehicles in the household. The third set of questions centers around the travel behavior of members of the household. These are the most detailed questions, and constitute the main dataset for this paper.

The travel diary starts by asking individuals where they began their day. A respondent reports the departure time from this starting point, the mode of transportation, and the time consumed on each leg of the day's travel. Finally, the travel diary includes the starting and end locations of each leg of travel, and asks the individuals for the general purpose of that travel. For some people, the travel diary is as simple as taking the subway to work, and then returning home using the same route. For others, the travel diary is complex. For example, many Beijing residents commute to work using a combination of modes, such as a subway ride followed by a bus trip. They may go to the supermarket or to a restaurant; they may take a taxi or walk to a lunch destination. Each of these individual trips is recorded in the travel diary data.

At our request, the BTRC added to the 2014 survey questions about whether members in the household entered the Beijing car lottery. The survey asked which members entered and their date of entry, as well as the date the individuals won. If they won, the survey asked whether and when they purchased a car. Our sample includes all individuals belonging to households with at least one lottery participant. About 20 percent of all households in the BTRC sample had at least one member participate in the lottery.

3 Empirical Strategy

3.1 Estimating Equations

The objective is to estimate the effect of owning an additional car on travel behavior outcomes such as total time and travel distance, and vehicle kilometers traveled (VKT). In general we would expect travel behavior to depend on the number of vehicles owned as well as demographics such as age or education. This relationship motivates a regression of travel behavior

outcomes on the number of household cars plus other controls:

$$Y_i = \mu + \alpha Cars_i + X_i\gamma + \varepsilon_i \quad (1)$$

where Y_i is the travel outcome for individual i , $Cars_i$ is the number of cars for the household of individual i , X_i is a vector of other covariates, and ε_i is a random error term. The vector X_i includes age, travel day fixed effects, and education group fixed effects. The coefficient of interest is α , the effect of the number of cars a household owns on VKT. Because we are particularly interested in the labor market consequences of cars, we consider whether the number of cars affects commuting VKT differently from VKT for other travel purposes.

Our primary variables of interest are total travel distance and VKT, as well as total travel time and vehicle travel time. Car ownership can increase or decrease total travel distance and time, because it affects the cost of transportation. Cars can reduce costs by reducing public transportation wait times, enabling more direct routes to destinations, and improving the comfort of trips. On the other hand, they can increase the cost of transportation because of Beijing's heavy traffic congestion. Even if reductions in time of travel are realized, these reduced costs can result in an increased number of trips, such as shopping in destinations that were previously inaccessible by public transportation. The net effect on total travel distance and time is ambiguous.

If we estimate equation 1 using ordinary least squares (OLS) we expect the estimate of α to be biased for several reasons. First, unobservable individual parameters such as driving preferences may be correlated with both the number of household cars and VKT. An individual who likes to drive is more likely to buy an additional car than an individual who prefers taking the subway. Second, there may be reverse causality, because owning a car may increase an individual's job opportunities, raising income and allowing the individual to purchase an additional car.

To address both sources of bias we restrict the sample to lottery participants and use the individual's lottery status to instrument for the number of cars. We predict the endogenous

number of cars using the equation

$$Cars_i = \lambda + \beta (Won\ the\ lottery)_i + \eta_i + X_i\chi + \mu_i \quad (2)$$

In theory, the lottery is both valid and relevant because it randomly allocates the option to purchase a car to entrants of the lottery. In equation 2, lottery entry month fixed effects, η_i , are necessary because early lottery entrants have higher probabilities of obtaining a car than later entrants because the earlier entrants participate in the lottery for more months and because success rates were higher in the early months. Moreover, members of households with stronger driving preferences may enter the lottery earlier than other households. Controlling for entry month implies that we are comparing lottery winners and losers who entered at the same time, controlling for potentially unobserved factors that are correlated with entry date. The coefficient β is identified by within-entry month variation.

Our second-stage equation is

$$Y_i = \mu + \alpha Cars_i + \eta_i + X_i\gamma + \varepsilon_i \quad (3)$$

This IV strategy is valid under two conditions: (a) conditional on date of entry, winning or losing the lottery is independent of all individual characteristics that might affect ε_i ; and (b) lottery status is a strong predictor of the number of cars. The next two subsections discuss whether both conditions are likely to hold.

3.2 The Comparability of Winners and Losers

To provide evidence supporting the first condition, we examine whether winning and losing households are similar along observable dimensions that are determined prior to the lottery. Finding that observable characteristics are not correlated with lottery status would decrease the likelihood that unobserved characteristics are correlated with lottery status.

While the sample we use in the previously described estimation includes only lottery en-

trants, we compare three samples here: lottery entrants, household heads, and all household members. The top panel of table 1 compares those individuals who entered and won the lottery with those who entered and did not win. The two groups have statistically indistinguishable gender compositions, birth years, education levels, and work statuses. This similarity supports the validity of the IV strategy using the sample of lottery entrants.

The middle panel of table 1 compares heads of household in families where at least one person entered the lottery. Winning households are those where at least one person won the lottery; losing households have no winners in the lottery. The heads of household in both winning and losing families are statistically very similar along the same dimensions.

The bottom panel compares all members in participating households. Winners include members in households where at least one person won the lottery and losers include members in households where no person has won the lottery. The fraction female and mean age of these households are quite similar; however, winners differ slightly in the graduation rates and the probability of working full-time.

We can explain these differences by analyzing the composition of members for households who won the lottery and those who did not. In the BTRC survey, all members of the household report their age and relationship to the head of household. Table 2 summarizes this information.

Winning households have 5 percent more people than losing households. At first, it may be puzzling that lottery winning households have more members than those that did not win the lottery. This difference in household size extends to both adults and children.

We suggest two explanations for the observation that winning households are larger than losing households. One explanation is that winning the lottery causes the household to have a child. A car may facilitate child care, or raise income by allowing access to a better job. The lottery began in 2011 and because we know birth year of all household members, we can test whether winning the lottery increases birthrates by counting the number of children born after 2011. In fact, the number of children born in 2011 or later per household is slightly larger in households winning the lottery. The lottery could not affect the birth of children born before

Table 1: Comparability of Individuals Winning and Not Winning the Lottery

	Winners	Losers	Difference
Lottery Entrants			
Female	0.389	0.409	-0.020
Birth year	1975.824	1975.791	0.033
High school graduation rate	0.847	0.860	-0.130
College graduation rate	0.628	0.624	0.003
Is working full-time	0.827	0.809	0.017
N	779	7,278	
Heads of Household			
Female	0.484	0.487	-0.002
Birth year	1967.791	1968	-0.593
High school graduation rate	0.728	0.743	-0.014
College graduation rate	0.449	0.472	-0.023
Is working full-time	0.626	0.658	-0.032*
N	762	6,268	
All Household Members			
Female	0.510	0.509	0.001
Birth year	1975.126	1974.970	0.157
High school graduation rate	0.657	0.676	-0.019*
College graduation rate	0.417	0.435	-0.018*
Is working full-time	0.551	0.569	-0.018*
N	2,404	18,845	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

2011, and the number of children born between 1996 and 2011 is statistically identical across winning and losing households.

There is also a significantly higher number of adult-age “children,” born before 1996, in winning households. In Chinese society, parents with young children often invite grandparents into the home to help with child care. In these three-generation families, the male grandparent constitutes the “head of household”, and the working adult in the family is recorded as the child of the head of household. As a result, a larger number of adult-age “children” are found in winning households.

Respondents also report whether they work full-time. Winning and losing households have a statistically indistinguishable number of the full-time employed. This further affirms the idea that households with cars live in three-generation homes more often, rather than separate households crowding into a single residence. Thus, we find suggestive evidence that car ownership affects household size and structure, which suggests that it would be inappropriate to include these variables as independent variables in equation 1.

The second possible explanation for the difference in household size across winning and losing households is that winning households may have more entrants. Because the lottery is randomized at the individual level, this would create a mechanical correlation between household size and the probability that at least one individual in the household won. The observable household-level differences between winning and losing households underscore the need to estimate equation 1 at the individual level and include only lottery participants. That is, conditional on entering the lottery, lottery status should be randomly assigned and uncorrelated with the error term. On the other hand, if winning the lottery causes a household to increase in size, or if winning is mechanically connected to household size, whether another individual in the household won the lottery may be correlated with unobservable attributes of nonparticipants. This correlation would bias estimates of equation 1 at the household level, but not at the individual level if the sample includes only lottery participants.

We also examined the possibility of recall bias; because some survey respondents are sur-

Table 2: Comparability of Households Winning and Not Winning the Lottery

	Winners	Losers	Difference
	By Age		
Number of members	3.136	2.989	0.148***
Number of adults (age 18 or older)	2.733	2.639	0.095***
Working adults	1.734	1.710	0.028
Lottery entrants	1.157	1.145	0.013
Number of children (below age 18)	0.421	0.368	0.053***
N	762	6,268	
	By Relationship with Head of Household		
Number of spouses	0.873	0.860	0.012
Number of children	0.904	0.819	0.085***
Born 2011 or later	0.093	0.068	0.025**
Born 1996 to 2011	0.219	0.226	-0.007
Born before 1996	0.592	0.524	0.068**
Number of parents	0.223	0.201	0.022
Number of grandchildren	0.125	0.094	0.030**
Number of grandparents	0.009	0.005	0.004
Number of siblings	0.004	0.008	-0.004
Number of other relatives	0.012	0.015	-0.003
Number of unrelated	0.005	0.004	0.001
N	762	6,268	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

veyed three years after entering they lottery, they may not accurately remember their date of entry or whether they won the lottery. We conducted many informal interviews with lottery entrants, which confirmed the accuracy of their recollections. Qualitatively speaking, obtaining a car seems important to them, and they seem to remember quite clearly details surrounding their participation in the lottery.

To examine the possibility of recall bias empirically, we report the characteristics of lottery entrants by their reported entry year in an appendix table. If recall bias affected the random assignment of winners and losers, the difference between the characteristics of winners and losers among 2011 entrants would be greater in magnitude than the corresponding differences between winners and losers that entered more recently. We do observe some marginally statistically significant differences between winners and losers among 2011 entrants, but there is no evidence that these differences are larger in magnitude than the differences between winners and losers among other entry years. While we cannot rule out recall bias, the evidence suggests that this is not a serious problem.³

3.3 First-Stage Estimates

Our IV estimates would be biased and inconsistent if lottery status were a weak predictor of the number of household cars. We therefore examine the effect of lottery status on vehicle ownership in table 3. Winning the lottery strongly increases car ownership. Individuals who do not win the lottery report 0.557 cars owned. Individuals who win the lottery report 1.213 cars owned, an increase of 0.656 cars that is statistically significant at the 1 percent level. Not all winners buy and keep a car, so this difference is less than one.⁴

³Differences in some characteristics between treatment and control groups can arise purely out of chance. Even differences of statistical significance are fairly common in pure lotteries, such as those in Dobbie and Fryer (2011).

⁴In addition, anecdotal evidence suggests that losing households may find ways to obtain cars. For example, some car dealerships hoarded license plates after the lottery policy was announced, and rented license plates to households on the condition that the household would return the license plate when it won the lottery. Alternatively, some large Beijing families had multiple members enter the lottery; the household member that needed the car the most then obtained primary access to the car. These anecdotes suggest that households that do not win the lottery find alternative methods to obtain a car, which should not bias our results as long as winning the lottery is

Table 3: The Effect of the Lottery on Ownership of Vehicles for Lottery Entrants

	Winners	Losers	Difference
	Vehicles Owned		
All vehicles	1.213	0.557	0.656***
Private vehicle	1.195	0.542	0.653***
Official vehicle	0.018	0.015	0.003
N	779	7,278	
	Characteristics of Vehicle		
Age of vehicle	2.442	4.061	-1.620***
Vehicle displacement	1.713	1.745	-0.032**
VKT per household	14,569	15,060	-491
VKT per vehicle	10,691	13,220	-2,529***
Fuel cost per vehicle	721.5	840.4	-118.9***
Fuel efficiency (cost/VKT)	0.102	0.100	0.002
Is a car (not truck or other)	0.991	0.976	0.015***
N	724	3,594	
	Other Forms of Transportation Owned		
Bicycles, pedal	1.010	1.103	-0.093***
Bicycles, electric	0.348	0.422	-0.074***
Motorcycles	0.036	0.046	-0.010
N	779	7,278	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Other parts of table 3 affirm the basic hypothesis that winning the lottery increases the number of cars in a household. Interestingly, households that won and lost the lottery both have roughly the same household VKT, but lottery winners have lower average VKT per vehicle. Because some lottery-winning households expand their car fleets from one to two vehicles, this allows each car to be driven less intensively.

Winning households have younger vehicles, reflecting the vintage of new cars purchased. Their cars are slightly smaller and fuel economy is almost identical.

Finally, we can observe how winning affects ownership of bicycles and motorcycles. Households that have not won the lottery own more bicycles, both pedaled and electric, reflecting their need to find alternative forms of transportation.

Table 4 reports the estimates of the first-stage regression of the number of household vehicles on lottery status (equation 2). The columns in the table report the estimates for both total travel and commuting of lottery entrants. We define “commute” as travel to get to an individual’s workplace for the purpose of work. The regressions include all of the variables in equation 1 that are assumed to be exogenous, such as age and education. For reasons discussed above, the sample includes only lottery participants. Consistent with the difference in the number of cars between winners and losers in table 3, in table 4 winning the lottery increases the number of household vehicles by about 0.65, an estimate that is statistically significant at the 1 percent level. The high degree of significance reduces concerns about weak instrument bias.

4 The Effect of Winning the Lottery on Travel Behavior

The sample includes only lottery participants, and table 5 presents our summary statistics describing the travel behavior of lottery entrants and other household members. Lottery entrants travel much longer distances than other household members.⁵ They travel much more by car,

exogenous to travel behavior.

⁵Ideally, we would be able to observe the distance traveled by observing the route selection of each person during each trip. Because this is not feasible, we estimate the daily distance traveled. First, we divide Beijing into approximately 1,600 traffic zones defined by the survey administrators. Each traffic zone is about 1 square

Table 4: First-Stage Regression for Number of Cars in the Household

	All Travel	Commute
Won the lottery	0.644*** (0.027)	0.648*** (0.032)
Age	-0.001* (0.001)	-0.001 (0.001)
Day of the week FE	Yes	Yes
Education of member FE	Yes	Yes
Entry date FE	Yes	Yes
N	7,015	5,556
R^2	0.115	0.122

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are robust and clustered at the city district level.

bus, subway, and taxi; other household members, primarily grandparents and children, walk and bike more. For both entrants and other members, the most important forms of transportation are the car and the bus, with subway and taxi use less frequent.

4.1 Main Results

4.1.1 OLS Regressions

Tables 6 and 7 report OLS regressions of travel distance and travel time on the number of cars owned by the household. The sample includes lottery participants.

These regressions include all predetermined attributes of both the household and individual that might relate to travel behavior, such as the individual's age, education level, and day of the week on which the interview was taken. The interview day is important because travel diaries are reported for the previous day's travel, and travel typically varies between weekdays and weekends.

The first column of each of these tables suggests that an additional car increases both total kilometer. In the travel survey, the origin and destination of each trip are placed into a traffic zone in Beijing, and the straight-line distances between the centroids of the pairs of traffic zones are calculated. Because the size of the traffic zones is small, this imputation likely introduces a small amount of measurement error.

Table 5: The Travel Behavior of Lottery Entrants and Other Household Members

	Entrant	Other Members	Difference	Household Average
All Travel				
Distance (km)	20.6	12.4	-8.2***	15.5
Car	6.5	4.1	-2.4***	5.0
Bus	7.0	3.4	-3.6***	4.7
Subway	3.4	1.4	-2.0***	2.1
Taxi	0.3	0.1	-0.2***	0.2
Walk/bike	3.3	3.4	0.1	3.4
Travel time (min)	69.9	49.9	-20.1***	57.5
Car	21.0	13.4	-7.7***	16.3
Bus	22.2	13.5	-8.6***	16.8
Subway	7.0	2.9	-4.0***	4.5
Taxi	0.8	0.4	-0.3**	0.6
Walk/bike	19.9	20.7	0.8	20.4
N	8,057	13,219		21,276
Commute				
Distance (km)	11.8	10.5	-1.2***	11.2
Car	3.2	3.7	0.4**	3.4
Bus	4.0	2.8	-1.2***	3.5
Subway	2.8	2.0	-0.8***	2.4
Taxi	0.1	0.1	-0.1*	0.1
Walk/bike	1.6	2.0	0.4***	1.8
Travel time (min)	36.4	34.5	-1.7**	35.6
Car	11.7	13.0	1.2**	12.3
Bus	11.4	8.8	-2.6***	10.1
Subway	2.0	1.4	-0.7***	1.7
Taxi	0.3	0.2	-0.2**	0.2
Walk/bike	10.8	11.5	-0.6	11.0
N	5,556	4,825		10,381

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 6: OLS Regressions on Total Travel Distance

	All Distance	By Car	By Bus	By Subway	By Bike/Foot
Lottery Entrants					
Number of cars	2.433*** (0.739)	9.475*** (0.495)	-3.724*** (0.559)	-1.984*** (0.287)	-1.093*** (0.164)
Age of member	-0.314*** (0.049)	-0.080*** (0.027)	-0.155*** (0.031)	-0.105*** (0.015)	0.029* (0.016)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	7015	7015	7015	7015	7015
R ²	0.029	0.102	0.035	0.063	0.049
Household Average					
Number of cars	2.044 (1.465)	7.808*** (0.876)	-2.777*** (0.684)	-1.826*** (0.592)	-0.919** (0.433)
Age of member	-0.158*** (0.036)	-0.026 (0.017)	-0.068*** (0.020)	-0.033*** (0.010)	-0.031** (0.012)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	7015	7015	7015	7015	7015
R ²	0.024	0.138	0.038	0.058	0.082

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are robust and clustered at the city district level.

Table 7: OLS Regressions on the Total Travel Time

	All Travel	By Car	By Bus	By Subway	By Bike/Foot
Lottery Entrants					
Number of cars	3.317** (1.192)	25.464*** (1.232)	-12.003*** (0.922)	-3.952*** (0.557)	-4.702*** (0.625)
Age of member	0.104 (0.095)	-0.013 (0.041)	-0.192*** (0.049)	-0.135*** (0.030)	0.421*** (0.083)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	8057	8057	8057	8057	8057
R ²	0.011	0.092	0.047	0.050	0.049
Household Average					
Number of cars	2.554*** (0.458)	18.693*** (0.773)	-8.286*** (0.596)	-2.448*** (0.298)	-4.364*** (0.530)
Age of member	0.259*** (0.048)	0.091*** (0.020)	0.054 (0.035)	0.029** (0.011)	0.078* (0.040)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	8057	8057	8057	8057	8057
R ²	0.020	0.176	0.061	0.055	0.049

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are robust and clustered at the city district level.

distance traveled and total daily travel time. Columns 2 through 5 decompose total travel time and distance by travel mode. Individuals in households with more cars travel much more using those cars, and much less using other forms of transportation, with bus travel showing the largest decrease followed by subway.⁶

4.1.2 IV Regressions

We expect the OLS estimates to yield biased results because of the endogeneity of the number of cars. Tables 8 and 9 present our IV results, which address this endogeneity by using lottery status to instrument for the number of cars. We control for lottery entry date to account for the possibility that entry date is correlated with driving preferences.

The coefficient in row 1 of table 8 for the effect of cars on total travel distance is 3.6 km, which is about 20 percent of the daily VKT reported in table 5. The coefficient in row 1 of table 9 for the effect of cars on travel time is 2.0 minutes, which is about 3 percent of average daily travel time.

As discussed above, car ownership can increase or decrease total travel distance and time. After controlling for the endogeneity of car ownership, adding a car to a household in Beijing does not affect either distance traveled or total travel time for the lottery entrant by a statistically significant amount. Given the point estimates on total travel distance, however, we cannot reject modest increases in distance traveled.

Obtaining a car has a large effect on mode of travel, as evidenced by the coefficients in columns 2 through 5 of both tables. To put our results in context, an additional car effectively replaces subway and bus travel.

Because the dependent variables in the top panels of tables 8 and 9 are measured at the individual level, the estimates do not reflect travel behavior of nonparticipants. To analyze aggregate household behavior, we compute the total household travel distance and time, and

⁶We also estimate corresponding regressions in which we replace the number of cars with an indicator variable equal to one if the household owns at least one car. The results are qualitatively similar: in households that own cars, individuals travel about the same distance, but car owners travel by car much more than non-car owners.

use these variables as dependent variables. The sample size is unchanged from the previous regressions because we use household averages for each lottery participant. We reiterate that the household composition has changed for lottery winning households. Since we believe this change in household composition is tied to the impact of winning the lottery, shifts in household membership should be regarded as a moderating factor in these estimates. That is, our estimates reflect the effect of car ownership on travel behavior net of any changes in household composition.

The bottom panels of both tables show that obtaining a car has similar effects on overall household travel behavior as on the lottery participants. Total distance traveled increases by 10 percent, but the estimate is not statistically significant. Total time traveled is essentially the same when the household adds a car; it increases by less than 1 percent. Again, there is a very large shift into driving and away from public transportation use and driving.

In summary, increasing the number of household cars has no effect on the time spent traveling. It may increase total travel distance but not by a statistically significant amount. Rather, the largest effect of increasing a household's cars is a shift in the method of transportation, with households moving most of their travel to driving. The largest substitute for driving is public transit, with car owners eliminating the use of buses and subways.

4.1.3 Commuting Behavior

Most lottery participants commute to work.⁷ In tables 10 and 11, we present IV estimates of the effect of the household's number of cars on commuting distance, at both the individual and household levels.

Similarly to our findings on total travel distance, we find that adding a car has no statistically significant effect on either the total commuting distance or time, for both lottery entrants and their households. To provide context for the point estimates, we note that the average lottery entrant commutes about 11.8 km per day for 37.0 minutes.

⁷We identify the workplace of survey participants by using the stated purpose of each trip. We study only the trip to work, because our data show that employees do not always return home directly from work.

Table 8: IV Regressions on Total Travel Distance

	All Distance	By Car	By Bus	By Subway	By Bike/Foot
Lottery Entrants					
Number of cars	3.640 (2.281)	12.268*** (1.679)	-4.835*** (1.024)	-2.683*** (0.739)	-0.822 (0.821)
Age of member	-0.312*** (0.048)	-0.075*** (0.027)	-0.157*** (0.030)	-0.106*** (0.016)	0.030* (0.015)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	7015	7015	7015	7015	7015
R ²	0.028	0.095	0.034	0.062	0.048
Household Average					
Number of cars	2.044 (1.465)	7.808*** (0.876)	-2.777*** (0.684)	-1.826*** (0.592)	-0.919** (0.433)
Age of member	-0.158*** (0.036)	-0.026 (0.017)	-0.068*** (0.020)	-0.033*** (0.010)	-0.031** (0.012)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	7015	7015	7015	7015	7015
R ²	0.0244	0.138	0.0386	0.0583	0.0823

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are robust and clustered at the city district level.

Table 9: IV Regressions on the Total Travel Time

	All Travel	By Car	By Bus	By Subway	By Bike/Foot
Lottery Entrants					
Number of cars	1.109 (4.367)	34.480*** (4.862)	-15.357*** (2.418)	-5.811*** (1.184)	-7.554*** (2.151)
Age of member	0.100 (0.091)	0.003 (0.040)	-0.198*** (0.047)	-0.139*** (0.029)	0.416*** (0.080)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	8057	8066	8066	8066	8066
R ²	0.010	0.082	0.045	0.048	0.047
Household Average					
Number of cars	0.250 (2.191)	16.788*** (1.740)	-7.903*** (1.101)	-2.706*** (0.721)	-4.397*** (1.448)
Age of member	0.256*** (0.046)	0.088*** (0.020)	0.054 (0.034)	0.028*** (0.011)	0.078** (0.038)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	8057	8066	8066	8066	8066
R ²	0.019	0.175	0.061	0.055	0.049

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are robust and clustered at the city district level.

The remainder of the basic story stays the same: owning a car increases the share of travel by car and reduces the shares by bus and subway. The coefficients from column 2 in these tables suggest that an additional car shifts about one-half of distance traveled and 40 percent of time spent traveling into car use from other travel modes.

4.1.4 Impacts on the Distribution of Commuting Distance for Lottery Entrants

The preceding results pertain to the effects of cars on mean travel distance and time, and we can also examine whether obtaining a car affects the full distribution of commuting distance. We define a series of indicator variables that are equal to one if the commute distance traveled is 0 to 5km, 5 to 10km, and so on. We repeat the IV regressions on the number of cars owned, except replacing commute distance as the dependent variable with the indicator variables for 5 km bands.

Results from these regressions are summarized in figure 1. The error bars on each point represent 95 percent confidence intervals on the estimate. Adding a car has a statistically distinguishable impact on those who commute 30 to 35 km, but there is a basically offsetting impact at the 35 to 40 km range. We do not show corresponding results for commute time for brevity, but there are very similar results for these.

4.2 Heterogeneous Impacts

We also examine whether the number of cars had a consistent effect on travel behavior for different household types. These results are relegated to the appendix tables for brevity.

First, we examine how the number of cars affects the travel behavior for full-time working household members of different ages. Specifically, we interact age with the number of cars, and instrument for the interaction using lottery status interacted with age (i.e., we continue to assume that age is exogenous to travel behavior).

Our results do not show any statistically significant impacts of car ownership or age on total travel distances for either total travel or commute. Again, the main shifts appear to occur in

Table 10: IV Regressions on Commute Travel Distance

	All Distance	By Car	By Bus	By Subway	By Bike/Foot
Lottery Entrants					
Number of cars	1.260 (1.388)	5.777*** (1.039)	-2.201*** (0.731)	-1.216* (0.637)	-1.098*** (0.185)
Age of member	-0.185*** (0.029)	-0.032* (0.017)	-0.076*** (0.015)	-0.095*** (0.015)	0.023*** (0.008)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	5556	5556	5556	5556	5556
R ²	0.030	0.102	0.026	0.055	0.061
Household Average					
Number of cars	1.247 (1.047)	4.353*** (0.632)	-1.374** (0.538)	-0.956 (0.600)	-0.765*** (0.153)
Age of member	-0.107*** (0.024)	-0.003 (0.014)	-0.044*** (0.010)	-0.058*** (0.012)	0.001 (0.006)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	5569	5569	5569	5569	5569
R ²	0.020	0.154	0.027	0.049	0.092

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are robust and clustered at the city district level.

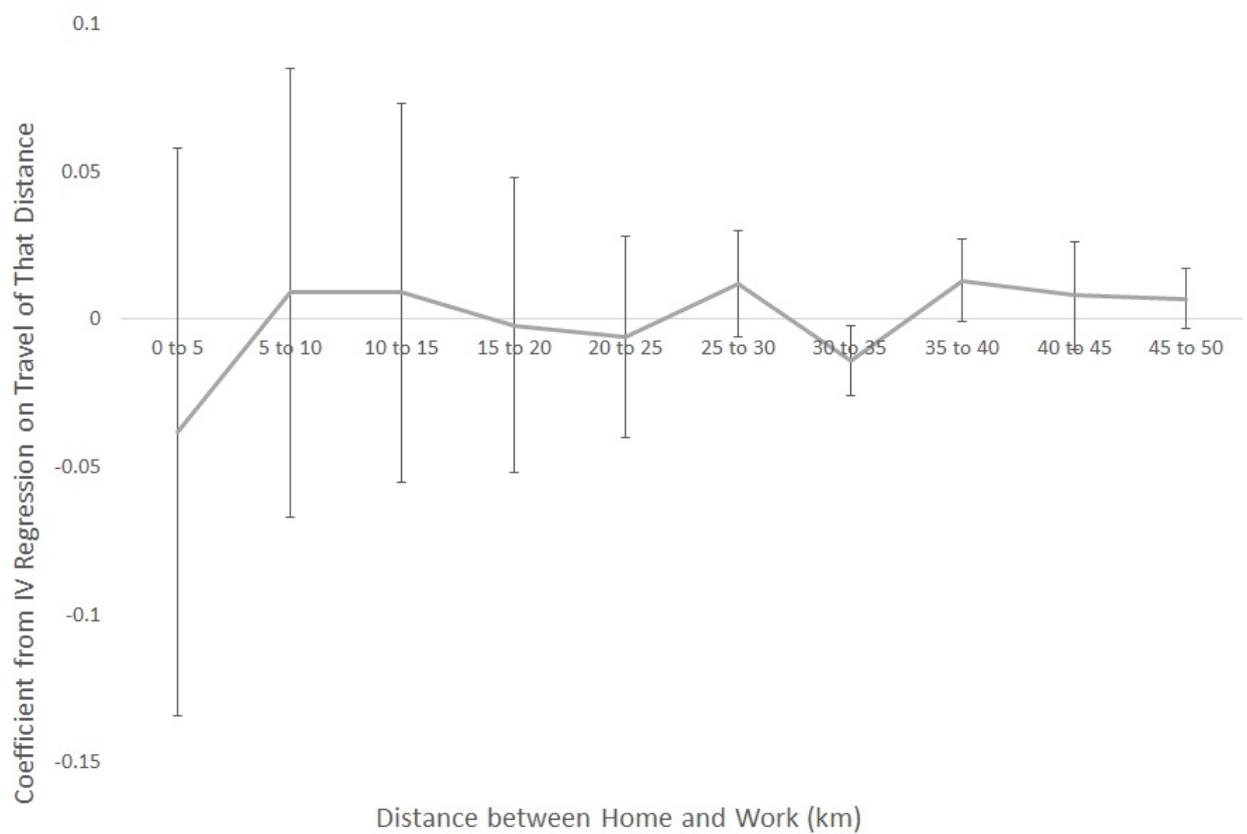
Table 11: IV Regressions on the Commute Travel Time

	All Travel	By Car	By Bus	By Subway	By Bike/Foot
Lottery Entrants					
Number of cars	-3.205 (4.520)	13.180*** (4.320)	-8.048*** (1.837)	-2.172*** (0.501)	-6.476*** (1.042)
Age of member	-0.162** (0.064)	-0.038 (0.049)	-0.189*** (0.050)	-0.050** (0.021)	0.122*** (0.041)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	4480	4480	4480	4480	4480
R ²	0.016	0.123	0.056	0.022	0.068
Household Average					
Number of cars	0.759 (1.911)	11.240*** (2.305)	-5.271*** (1.467)	-2.032*** (0.382)	-3.387** (1.355)
Age of member	-0.053 (0.036)	0.019 (0.031)	-0.084** (0.039)	0.003 (0.016)	0.009 (0.033)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	5030	5030	5030	5030	5030
R ²	0.024	0.186	0.061	0.031	0.077

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are robust and clustered at the city district level.

Figure 1: Results on IV Regressions for the Distribution of Commute Distance for the Full-Time Employed.



the mode of transportation. Although the age interactions are not statistically significant for total distance and car distance (for both commuting trips and all trips), the age interactions are positive and statistically significant for all bus and subway travel and for commuting travel by bus. These results suggest that obtaining a car may cause older individuals to reduce bus or subway travel less than do younger individuals, perhaps because of differential preferences for car use across age groups.

Second, we examine how entry date might affect travel behavior. Early lottery entrants may have had the highest demand for cars or they may have had more time to make significant adjustments in their lives in response to a car, such as changing jobs or housing. In these regressions, we interact entry year fixed effects with the number of cars, and instrument for these interactions using lottery status interacted with entry year.

We find no statistically significant effects of entry date on travel behavior. The differences across entry years show no obvious pattern. Relative to the 2011 entrants, our point estimates suggest that 2013 entrants increased their total travel more, but 2014 entrants decreased travel. For commuting distance, 2012 entrants increased travel distance more than 2011 entrants, and 2014 entrants decreased travel. In no cases are the entry year interactions statistically significant for total distance or car distance. We conclude that date of entry seems to have no impact on our primary results.

5 Implications

This section discusses three immediate implications of the estimated effects of car ownership on travel behavior.

First, our methodology allows us to show that the effect of the lottery on overall car use in Beijing has been large. We use our estimates of the effect of the lottery on car ownership, combined with the estimated effect of car ownership on VKT, to derive a rough estimate of the effect of the lottery on overall car use.

We begin by assuming that if the lottery had not existed, individuals in households who entered the lottery and lost would have been as likely to purchase a car as individuals who entered the lottery and won. This assumption is supported by the observation that winners and losers are quite similar along observable dimensions (see table 1). Implicitly, we are assuming the lottery per se does not affect the probability that a winner purchases a car. We also assume that individuals who do not enter the lottery would not have purchased a car in the absence of the lottery policy. Supporting this assumption is the fact that the cost of entering the lottery was near zero.

Under the first assumption, lottery losers would have purchased on average about 0.65 additional cars (see table 4). This estimate is consistent with table 3, and shows that the lottery reduced the number of cars for lottery losers by more than half. We multiply this estimate by the number of cars in the sample to determine that, in the sample, the Beijing lottery removed 4,692 new cars removed from the road. The full BTRC sample (which includes nonparticipants) has 19,217 cars among those surveyed. Assuming that this survey is representative of Beijing and employing the second assumption that nonparticipants would not have purchased a car in the absence of the lottery, this implies that the lottery reduced the total number of cars in Beijing by 19.6 percent.

We estimate the VKT reduction in Beijing through similar methods. According to IV estimates of equation 1, adding a car increases VKT by 7.8 km per person. Therefore, if the lottery had not existed, VKT would have been $0.65 \text{ cars} * 7.7 \text{ km} = 5.0 \text{ km}$ higher per person. Because losing members constituted the majority of the sample and losers drive only 4.7 km per person, we find the lottery decreased driving among all lottery participants by 47 percent. Because lottery participants accounted for 12 percent of the 336,298 VKT in the full BTRC survey in Beijing, we conclude that at the time of the survey the lottery reduced VKT in Beijing by 9.9 percent.⁸

⁸We find that the lottery reduced the number of cars by 19.8 percent and VKT by 9.9 percent. The difference between these two numbers comes from the fact that lottery entrants appear to drive their cars somewhat less than the households surveyed in the full BTRC survey. This stresses the point that our findings hold only over the set of lottery entrants.

The second implication follows from the finding that car ownership does not have a large effect on commute travel distance and time. In Beijing, which has a well-developed public transportation system, restricting car ownership has not had a discernible effect on the time cost of commuting to work. The previous literature has consistently found that car ownership reduces commuting costs and increases job opportunities, implying that restrictions in vehicle ownership would raise commuting costs and reduce job opportunities. In Beijing, and possibly in other cities with dense public transportation, these concerns may be overstated. Another possibility is that car ownership did not expand the set of job opportunities enough to detect an effect.

The third implication follows from the finding that car ownership increases car use roughly one-for-one. Members of losing households own 0.56 cars and drive 4.7 km, suggesting that as a baseline each car is driven 8.4 km per member. The IV estimates imply that an additional car adds 7.7 km per household member, which is close to the baseline travel amount.

In addition, cars seem to influence the number of babies that Beijing families have and increase family sizes; we speculate that this is because cars make child care and elderly care more convenient. These benefits should be considered by policy makers, and traded off against the significant cost of cars in the form of increased congestion, pollution, and greenhouse gas emissions.

The finding that car ownership raises VKT on a nearly one-for-one basis has implications for long-run growth in vehicle use and fuel consumption. If the proportional relationship holds more broadly, it suggests that future fuel consumption, pollution emissions, and vehicle usage are roughly proportional to vehicle ownership. Thus, projecting fuel consumption and pollution emissions depends largely on projecting vehicle ownership, a finding that may be useful in the important literature on vehicular contributions to environmental problems.

We offer a caveat to the last conclusion, however. The lottery has reduced car use and may also have affected traffic congestion. To the extent that car use increased because of the lower congestion, our results would overestimate the effect of future growth in car ownership

on vehicle use.

6 Conclusions

Understanding the relationship between car ownership and use in developing countries is important for characterizing historical and future growth in car use and traffic congestion, as well as evaluating the costs and benefits of policies that aim to reduce vehicle use by restricting ownership. The major challenge to evaluating this relationship empirically has been the endogeneity of vehicle ownership, which is likely to be correlated with potentially unobserved determinants of vehicle use.

We address this challenge by exploiting variation in household vehicle ownership induced by Beijing's license plate lottery system, combined with highly detailed information on vehicle use. We find that new cars are used intensively and replace travel by other modes on a roughly one-for-one basis; car ownership does not have a statistically significant effect on total travel distance or time.

Our results imply that the lottery system has substantially reduced vehicle use while not impacting either total travel distance and time, or commute distance and time. This suggests that labor market consequences of restricting ownership may be modest.

We offer a few caveats related to the external validity of our findings, besides those already noted. First, we have noted that our main findings contrast with those from previous research. The discrepancy could arise from the fact that past research does not fully address the endogeneity of vehicle ownership, but it could also reflect the idiosyncracies of Beijing, which combines notoriously dense congestion with an extensive public transportation system. Our work is likely most applicable to other large cities with these properties.

Second, car ownership restrictions may reduce congestion (Yang et al. 2014) and increase the value and use of new cars. The effects on car use of newly-enacted ownership restrictions, such as the Beijing license plate lottery, may differ from the effects of long-standing policies.

Finally, the mechanism of the lottery required only an online application and was free of charge. As a result, some Beijing residents entered the lottery because they anticipated the possibility of needing a car, and purchased a car when they won because they did not expect to be able to win a second time. Many lottery winners also did not add vehicles to their households. Therefore, the lottery should be regarded as a random mechanism over those who wanted an *option* to purchase a car, rather than those who wanted a car.

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Appendix Table 1: Comparability of Lottery Entrants Winning and Not Winning the Lottery, by Year of Entry

	Winners	Losers	Difference
		2011	
Female	0.381	0.377	0.004
Birth year	1975.6	1974.5	1.144*
High school graduation rate	0.876	0.862	0.014
College graduation rate	0.668	0.620	0.047*
Is working full-time	0.841	0.800	0.041*
N	346	1,805	
		2012	
Female	0.383	0.393	-0.010
Birth year	1976.6	1975.5	1.141
High school graduation rate	0.825	0.851	-0.027
College graduation rate	0.606	0.611	-0.006
Is working full-time	0.836	0.827	0.008
N	274	2,301	
		2013	
Female	0.432	0.430	0.002
Birth year	1975.0	1976.6	-1.639
High school graduation rate	0.841	0.857	-0.016
College graduation rate	0.591	0.619	-0.028
Is working full-time	0.773	0.814	-0.041
N	132	2,002	
		2014	
Female	0.333	0.457	-0.124
Birth year	1973.9	1976.9	-3.00
High school graduation rate	0.741	0.880	-0.139**
College graduation rate	0.519	0.662	-0.143
Is working full-time	0.815	0.781	0.033
N	27	1,171	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix Table 2: IV Regressions on Total Travel Distance with Age Interactions for Lottery Entrants

	All Distance	By Car	By Bus	By Subway	By Bike/Foot
	All Travel				
Number of cars	0.288 (7.123)	16.835*** (5.652)	-10.040*** (3.239)	-6.134*** (2.005)	-1.534 (1.223)
(Number of cars)*(Age)	0.088 (0.165)	-0.120 (0.137)	0.136** (0.067)	0.090** (0.036)	0.019 (0.045)
Age of member	-0.364*** (0.092)	-0.005 (0.071)	-0.237*** (0.054)	-0.159*** (0.033)	0.019 (0.029)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	7015	7015	7015	7015	7015
R ²	0.028	0.096	0.035	0.062	0.048
	Commute				
Number of cars	-0.080 (5.192)	7.932* (4.154)	-6.508*** (2.001)	-1.850 (2.042)	0.028 (0.566)
(Number of cars)*(Age)	0.037 (0.130)	-0.059 (0.107)	0.119*** (0.044)	0.017 (0.041)	-0.031* (0.018)
Age of member	-0.207*** (0.079)	0.003 (0.061)	-0.146*** (0.030)	-0.106*** (0.034)	0.041*** (0.016)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	5556	5556	5556	5556	5556
R ²	0.030	0.104	0.025	0.056	0.060

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are robust and clustered at the city district level.

Appendix Table 3: IV Regressions on Total Travel Distance with Year of Entry Interactions for Lottery Entrants

	All Distance	By Car	By Bus	By Subway	By Bike/Foot
	All Travel				
Number of cars	1.684 (3.164)	11.907*** (2.575)	-4.975*** (1.751)	-3.703*** (0.711)	-1.065** (0.497)
(Number cars)*(2012 entry)	2.359 (3.427)	-0.586 (3.247)	2.338 (2.215)	1.304 (1.133)	-0.534 (0.979)
(Number cars)*(2013 entry)	6.412 (4.833)	3.499 (4.470)	-4.455** (2.258)	2.915 (2.132)	2.856 (3.963)
(Number cars)*(2014 entry)	-3.635 (9.392)	-1.109 (8.441)	0.624 (5.950)	-0.038 (4.324)	-2.068 (2.335)
Age of member	-0.313*** (0.048)	-0.076*** (0.027)	-0.156*** (0.030)	-0.106*** (0.015)	0.029** (0.015)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	7019	7019	7019	7019	7019
R ²	0.025	0.092	0.025	0.058	0.039
	Commute				
Number of cars	0.508 (1.730)	5.843*** (1.313)	-1.859** (0.937)	-2.307*** (0.463)	-1.035*** (0.313)
(Number cars)*(2012 entry)	1.996 (1.762)	0.061 (1.576)	0.615 (1.561)	1.661 (1.122)	-0.322 (0.404)
(Number cars)*(2013 entry)	0.314 (2.519)	-0.415 (1.889)	-2.813** (1.305)	2.361 (1.598)	0.372 (0.350)
(Number cars)*(2014 entry)	-1.194 (3.590)	-0.453 (3.565)	-2.273 (2.435)	1.800 (3.906)	-0.195 (0.907)
Age of member	-0.184*** (0.030)	-0.031* (0.017)	-0.074*** (0.015)	-0.096*** (0.015)	0.023*** (0.008)
Day of the week FE	Yes	Yes	Yes	Yes	Yes
Education FE	Yes	Yes	Yes	Yes	Yes
Entry date FE	Yes	Yes	Yes	Yes	Yes
N	5556	5556	5556	5556	5556
R ²	0.028	0.103	0.014	0.049	0.061

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Standard errors are robust and clustered at the city district level.