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% and car miles by 10% 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 the ownership and usage of cars. In cities like 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 localities like 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: restricting vehicle ownership may adversely affect the labor market by increasing travel times and costs, and reducing job opportunities.[1] If these effects are large, vehicle restriction policies could harm long-run economic growth.

Both the growth in car ownership and the rise of policies restricting ownership and use point to a central question: how does car ownership affect travel behavior? The manageability of congestion and air pollution will depend not only on vehicle ownership rates but on how those 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. Despite the importance of vehicle ownership and travel behavior, little is known about these important issues.

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

A sizeable 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 unobserved characteristics that are correlated with both 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.

A few papers, including 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 that favor driving may enact favorable policies. A number of studies have attempted to address the endogeneity of vehicle use by simultaneously modeling vehicle ownership and use (e.g., West 2004 and Bento et al. 2009), but these cannot overcome the problem of confounders that are unobserved. In addition, all of these studies pertain to developed countries and rely on functional form assumptions to address the endogeneity of vehicle ownership.

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% 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 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 validity of the instrumental variable (IV) approach. The lottery outcome is a valid instrument if it is uncorrelated with unobserved determinants of travel behavior and if it is a strong predictor of vehicle ownership. If the lottery outcome is uncorrelated with unobservables, we would 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 find that the means of the attributes of lottery winners and losers are statistically indistinguishable from one another. Furthermore, winning the lottery is a strong predictor of car ownership. 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. 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 effect on total household travel distance, and no effect on travel time.

We next investigate how vehicles miles traveled is affected by adding a car, and find that one additional car roughly doubles distance traveled by car while decreasing travel by bus, subway, and foot. 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. Car owners drive more and substitute from other forms of transportation on a roughly one-to-one basis.

Because the commute to work can affect labor outcomes, we particularly focus on reported trips to work. Here, our surprising finding is that vehicle ownership has a very similar pattern of results: there is a small and not statistically significant effect on commuting distance and no effect on commute time. Instead, obtaining a car reduces bus and subway trips that have roughly the same distance and time as the car trips. This is in sharp contrast to prior work like Gautier and Zenou (2010) and Holzer et al. (1994), who found that cars are associated with lower travel times and longer distance traveled.

We draw three direct implications from these results. First, the major welfare costs of restricting vehicle use could include an increase in commute travel time, decrease in job opportunities, and disutility of public transportation compared to driving. However, having a new car does not result in a statistically significant increase on either commute distance traveled or time of travel. In cities like Beijing that have dense public transportation systems, policies limiting the growth of car ownership will have very low impacts on the cost of commuting to work. These results suggest that, in the setting of Beijing, much of the welfare costs would be confined to the disutility of public transportation.

Second, people obtaining cars reduce other travel modes and use their cars intensively. These changes occur across most types 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 the distance traveled by a statistically significant or large amount, households exhibit a strong preference for using cars when they are available.

However, it is noteworthy that driving distance quickly increases with the number of cars a household owns: adding a car nearly doubles driving distance. Wolfram et al. (2012) suggest that vehicle ownership may increase more quickly in developing countries than indicated by current projections, and that those projections may therefore understate future growth in fuel consumption and pollution emissions. However, their analysis does not account for the possibility that average vehicle use varies with total vehicle ownership. Despite this possibility, our results imply that as ownership increases over time average use per vehicle will not change, and that driving and fuel consumption will increase proportionately with ownership—that is, our results underscore their conclusion that existing forecasts of fuel consumption in developing countries may be understated.

Third, the lottery system has reduced vehicle ownership by 19.8 percent and total travel distance in Beijing by 9.9 percent. These are large decreases and suggest that the Beijing vehicle restriction policies have had a substantial impact over its three years.

These conclusions 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 has not added 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.

This discussion 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 5th ring road between the hours of 7:00 a.m. to 9:00 a.m. and 5:00 p.m. to 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 cars sales had grown at an average rate of 31% between 2001-2010 in Beijing, and reached a height of over 76,000 cars per month during 2010. During the first drawing, there were ten times as many lottery applicants as license plates available, and the probability of success 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 during a given month fell to less than 2%, and the success rate fell below 1% in 2015.

Yang et. al (2014) point out that, 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% of individual lottery winners did not purchase a car, and 22.8% 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, 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 center around the travel behavior of members of the household. These are the most detailed questions, and constitute the main dataset for the purposes of 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 point 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. This sample constitutes XX percent of the full BTRC sample.

3 Empirical Strategy

3.1 Estimating Equations

The objective is to estimate the effect of owning an additional car on travel behavior variables such as vehicle kilometers traveled (VKT) and time spent traveling. For the sake of exposition, the discussion of the empirical strategy focuses on the distance variable of VKT.

In general we would expect VKT to depend on the number of vehicles owned as well as demographics such as age or education. This relationship motivates a regression of VKT on the number of household cars plus other controls:

$$Y_i = \mu + \alpha Cars_i + X_i \gamma + \varepsilon_i \tag{1}$$

where Y_i is the distance traveled for individual i, $Cars_i$ is the number of cars for the household of individual i, X_i is a vector of other covariates discussed below, and ε_i is a random error term. 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 VKT and time spent traveling. For each of these variables, we examine both the behavior of the lottery entrant, and the behavior of her household.

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 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:

$$Cars_i = \lambda + \beta \left(Won\, the\, lottery\right)_i + X_i \chi + \mu_i \tag{2}$$

This IV strategy is valid under two conditions: (a) conditional on 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 show that the first of these conditions holds, we examine whether winning and losing households are similar along observable dimensions. Finding that observable characteristics are not correlated with lottery status would decrease the likelihood that unobserved characteristics are correlated with lottery status.

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.

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 of men and women 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 that 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 children born 2011 or late in each household is slightly larger in households winning the lottery. The birth of children born before 2011 could not be affected by the lottery, and we see that the number of children born between 1996 and 2011 in winning and losing

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

	Winners	Losers	Difference
		Lottery Entrants	
Female	0.388	0.409	-0.022
Birth year	1976	1976	0.012
High school graduation rate	0.848	0.860	-0.126
College graduation rate	0.626	0.624	0.003
Is working full time	0.825	0.809	0.015
N	781	7,285	
		Heads of Household	
Female = 1	0.484	0.487	-0.002
Birth year	1968	1968	-0.593
High school graduation rate	0.729	0.742	-0.013
College graduation rate	0.448	0.472	-0.024
Is working full time	0.624	0.658	-0.033*
N	764	6,275	
		All Household Members	
Female	0.510	0.509	0.001
Birth year	1975	1975	0.151
High school graduation rate	0.657	0.676	-0.019*
College graduation rate	0.416	0.434	-0.018*
Is working full time	0.550	0.569	-0.019*
N	2409	18,867	

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

households is statistically identical.

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 childcare. In these three-generation families, the male grandparent will then constitute the "head of household", and the working adult in the family will be recorded as the child of the head of household. As a result, a larger number of adult-age "children" will be found in winning households.

Respondents also answer when 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 non-participants. 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.

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

	Winners	Losers	Difference
		By Age	
Number of members	3.135	2.989	0.146***
Number of adults	2.733	2.639	0.094***
Working adults	1.734	1.710	0.024
Lottery entrants	1.157	1.445	0.013
Number of children	0.420	0.368	0.052***
		By Relationship with Household Head	
Number of spouses	0.873	0.860	0.013
Number of children	0.903	0.819	0.084***
Born 2011 or later	0.093	0.068	0.025**
Born 1996 to 2011	0.219	0.226	-0.008
Born before 1996	0.592	0.524	0.067**
Number of parents	0.223	0.201	0.022
Number of grandchildren	0.124	0.095	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	781	7285	

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

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 stats 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 1.196 cars owned, an increase of 0.655 cars that is statistically significant at the 1% level. The fact that this difference is less than one suggests that not all winners buy and keep a car.[2]

Other parts of table 3 affirm the basic hypothesis that winning the lottery increases the number of cars in a household. Winning the lottery increases household VKT and reduces average VKT per vehicle. Because some lottery-winning households expand their car fleet 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 a destination where the respondent works. 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

[2]In 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 many 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, and should not bias our results as long as winning the lottery is exogenous to travel behavior.

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	0.655***
Private vehicle	1.195	0.542	0.652***
Official vehicle	0.018	0.015	0.002
N	781	7,285	
		Characteristics of Vehicle	
Age of vehicle	3.151	4.525	-1.374***
Vehicle displacement	1.713	1.745	-0.032**
VKT per household	13,526	7,442	6,085***
VKT per vehicle	10,684	13,218	-2,534***
Fuel cost per vehicle	721.0	840.0	-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	726	3,599	
		Other Forms of Transportation Owned	
Bicycles, pedal	1.009	1.103	-0.094***
Bicycles, electric	0.347	0.422	-0.075***
Motorcycles	0.036	0.046	-0.010
N	781	7,285	

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

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

	All Travel	Commute
Won the Lottery	0.648***	0.664***
	(0.026)	(0.033)
Age	-0.001	-0.001
	(0.001)	(0.001)
Day of the week FE	Yes	Yes
Education of member FE	Yes	Yes
N	8,066	5,573
R^2	0.096	0.105

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
Standard errors are robust and clustered at the city district level.

vehicles by about 0.65, an estimate that is statistically significant at the one percent level. The high degree of significance reduces concerns about weak instrument bias.

4 The Effect of Winning the Lottery on Travel Behavior

Because the sample includes only lottery participants, 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.[3] They travel much more by car, bus, subway, and taxi; other household members, primarily grandparents and children, walk and bike more. For both the full-time employed and other members, the most important forms of transportation are the car and the bus, with subway and taxi use less frequent.

[3]Ideally, 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. Each traffic zone is about 1 square 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	0.7	3.4
Travel time (min)	69.9	49.9	-20.1***	57.5
Car	21.0	13.4	-7.6***	16.3
Bus	22.1	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	0.7	20.4
N	8,066	13,210		21,276
		Commute		
Distance (km)	11.8	10.5	-1.2***	11.2
Car	3.2	3.7	0.5**	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)	37.0	35.2	-1.8***	36.1
Car	12.2	13.4	1.2*	12.8
Bus	11.4	8.8	-2.6***	10.2
Subway	2.1	1.4	-0.7***	1.7
Taxi	0.5	0.2	-0.3***	0.3
Walk/Bike	10.7	11.4	0.7	11.0
N	4,579	4,244		8,825

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

Table 6: OLS Regressions on Total Travel Distance

	All Distance	By Car	By Bus	By Subway	By Bike/Foot
	For Lottery Entrants				
Number of cars	2.271***	9.459***	-3.814***	-2.013***	-1.104***
	(0.705)	(0.505)	(0.521)	(0.276)	(0.162)
Age of member	-0.322***	-0.0808***	-0.158***	-0.107***	0.0284*
	(0.0485)	(0.0265)	(0.0297)	(0.0152)	(0.0162)
[1em] N	7024	7024	7024	7024	7024
R^2	0.0198	0.0967	0.0296	0.0569	0.0443
	Household Average				
Number of cars	2.466***	8.402***	-3.026***	-1.614***	-1.062***
	(0.428)	(0.369)	(0.311)	(0.171)	(0.145)
Age of member	-0.163***	-0.0275	-0.0697***	-0.0334***	-0.0307**
	(0.0385)	(0.0176)	(0.0207)	(0.0104)	(0.0132)
N	7024	7024	7024	7024	7024
R^2	0.0152	0.133	0.0325	0.0531	0.0777

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

All regressions include fixed effects for the day of the week of the interview and the education member of the individual. Standard errors are robust and clustered at the city district level.

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 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.

Table 7: OLS Regressions on the Total Travel Time

	All Distance	By Car	By Bus	By Subway	By Bike/Foot
	Lottery Entrants				
Number of cars	3.398***	25.65***	-12.07***	-3.978***	-4.745***
	(1.164)	(1.196)	(0.908)	(0.543)	(0.623)
Age of member	0.105	-0.00277	-0.189***	-0.134***	0.417***
	(0.0973)	(0.0391)	(0.0480)	(0.0283)	(0.0807)
N	8066	8066	8066	8066	8066
R^2	0.00657	0.0882	0.0418	0.0471	0.0434
	Household Average				
Number of cars	2.380***	18.58***	-8.328***	-2.470***	-4.374***
	(0.414)	(0.732)	(0.602)	(0.286)	(0.521)
Age of member	0.251***	0.0857***	0.0535	0.0288**	0.0772*
	(0.0473)	(0.0201)	(0.0346)	(0.0113)	(0.0394)
N	8066	8066	8066	8066	8066
R^2	0.0128	0.171	0.0548	0.0503	0.0430

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

All regressions include fixed effects for the day of the week of the interview and the education member of the individual. Standard errors are robust and clustered at the city district level.

The first column of these tables suggests that an additional car increases both total distance traveled and total daily travel time. Columns 2-5 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.[4]

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.

The coefficient in row 1 for the effect of cars on travel distance is 3.2 km, which is about 15 percent of the daily VKT reported in table 5. The coefficient in row 1 for the effect of cars on travel time is 2.4 minutes, which is about 3 percent of average daily travel time.

After controlling for the endogeneity of car ownership, adding a car to a household in Beijing does not increase 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 2-5 of both tables. To put our results in context, each additional car increases the share of cars in both distance traveled and time traveled by more than one-half. These increases are largely offset by decreases in other forms of transportation, particularly bus and subway ridership.

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 non-participants. To analyze aggregate household behavior, we compute the total household travel distance and time, and use

[4] We 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.

these variables as dependent variables. 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%, 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%. 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 using buses and subways much less.

4.1.3 Commuting Behavior

Most of the lottery participants commute to work.[5] In tables 10 and 11, we present IV estimates of the effect of the household's number of cars on commuting distance, both at the individual and household levels.

Similar 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.

The remainder of the basic story remains 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.

[5] We identify the workplace of survey participants by using the stated purpose of each trip. We study only the trip into work, because our data show that employees do not always return home immediately after work.

Table 8: IV Regressions on Total Travel Distance

	All Distance	By Car	By Bus	By Subway	By Bike/Foot
			For Lottery Entrants		
Number of cars	3.176	12.32***	-5.301***	-2.710***	-0.843
	(2.103)	(1.624)	(0.988)	(0.636)	(0.747)
Age of member	-0.321***	-0.0770***	-0.160***	-0.108***	0.0288*
	(0.0475)	(0.0265)	(0.0290)	(0.0154)	(0.0158)
N	7024	7024	7024	7024	7024
R^2	0.0194	0.0883	0.0270	0.0555	0.0440
			Household Average		
Number of cars	1.600	7.679***	-3.017***	-1.795***	-0.992**
	(1.428)	(0.861)	(0.698)	(0.530)	(0.407)
Age of member	-0.164***	-0.0285*	-0.0697***	-0.0337***	-0.0306**
	(0.0374)	(0.0172)	(0.0203)	(0.0104)	(0.0126)
N	7024	7024	7024	7024	7024
R^2	0.0144	0.132	0.0325	0.0529	0.0776

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

All regressions include fixed effects for the day of the week of the interview and the education member of the individual. 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	2.380	35.82***	-15.64***	-5.714***	-7.654***
	(4.110)	(4.767)	(2.488)	(1.074)	(1.841)
Age of member	0.104	0.0104	-0.194***	-0.136***	0.413***
	(0.0939)	(0.0394)	(0.0460)	(0.0273)	(0.0779)
N	8066	8066	8066	8066	8066
R^2	0.00647	0.0745	0.0393	0.0449	0.0412
			Household Average		
Number of cars	0.265	16.89***	-8.057***	-2.753***	-4.276***
	(2.156)	(1.717)	(1.146)	(0.645)	(1.347)
Age of member	0.249***	0.0844***	0.0537	0.0286***	0.0773**
	(0.0460)	(0.0196)	(0.0334)	(0.0111)	(0.0381)
N	8066	8066	8066	8066	8066
R^2	0.0115	0.170	0.0548	0.0500	0.0430

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

All regressions include fixed effects for the day of the week of the interview and the education member of the individual. Standard errors are robust and clustered at the city district level.

Table 10: IV Regressions on Commute Travel Distance

	All Distance	By Car	By Bus	By Subway	By Bike/Foot
	Lottery Entrants				
Number of cars	1.513	6.359***	-2.266***	-1.375**	-1.034***
	(1.245)	(0.989)	(0.630)	(0.560)	(0.186)
Age of member	-0.186***	-0.0293*	-0.0811***	-0.0952***	0.0213***
	(0.0305)	(0.0172)	(0.0162)	(0.0147)	(0.00755)
N	5666	5666	5666	5666	5666
R^2	0.0169	0.0885	0.0168	0.0486	0.0527
	Household Average				
Number of cars	1.244	4.859***	-1.462***	-1.254**	-0.750***
	(1.017)	(0.660)	(0.467)	(0.492)	(0.143)
Age of member	-0.106***	-0.00313	-0.0477***	-0.0557***	-0.0000920
	(0.0257)	(0.0136)	(0.0118)	(0.0120)	(0.00606)
N	5679	5679	5679	5679	5679
R^2	0.0119	0.144	0.0195	0.0455	0.0845

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

All regressions include fixed effects for the day of the week of the interview and the education member of the individual. 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	-3.477	13.83***	-8.465***	-2.308***	-6.763***
	(3.897)	(3.683)	(1.759)	(0.627)	(0.918)
Age of member	-0.163**	-0.0361	-0.189***	-0.0476**	0.118***
	(0.0640)	(0.0490)	(0.0508)	(0.0209)	(0.0400)
N	4483	4483	4483	4483	4483
R^2	0.00556	0.115	0.0464	0.0143	0.0576
			Household Average		
Number of cars	0.334	11.42***	-5.468***	-2.051***	-3.740***
	(1.679)	(2.042)	(1.364)	(0.429)	(1.219)
Age of member	-0.0510	0.0247	-0.0825**	0.00466	0.00374
	(0.0361)	(0.0299)	(0.0357)	(0.0164)	(0.0325)
N	5034	5034	5034	5034	5034
R^2	0.0140	0.180	0.0537	0.0215	0.0694

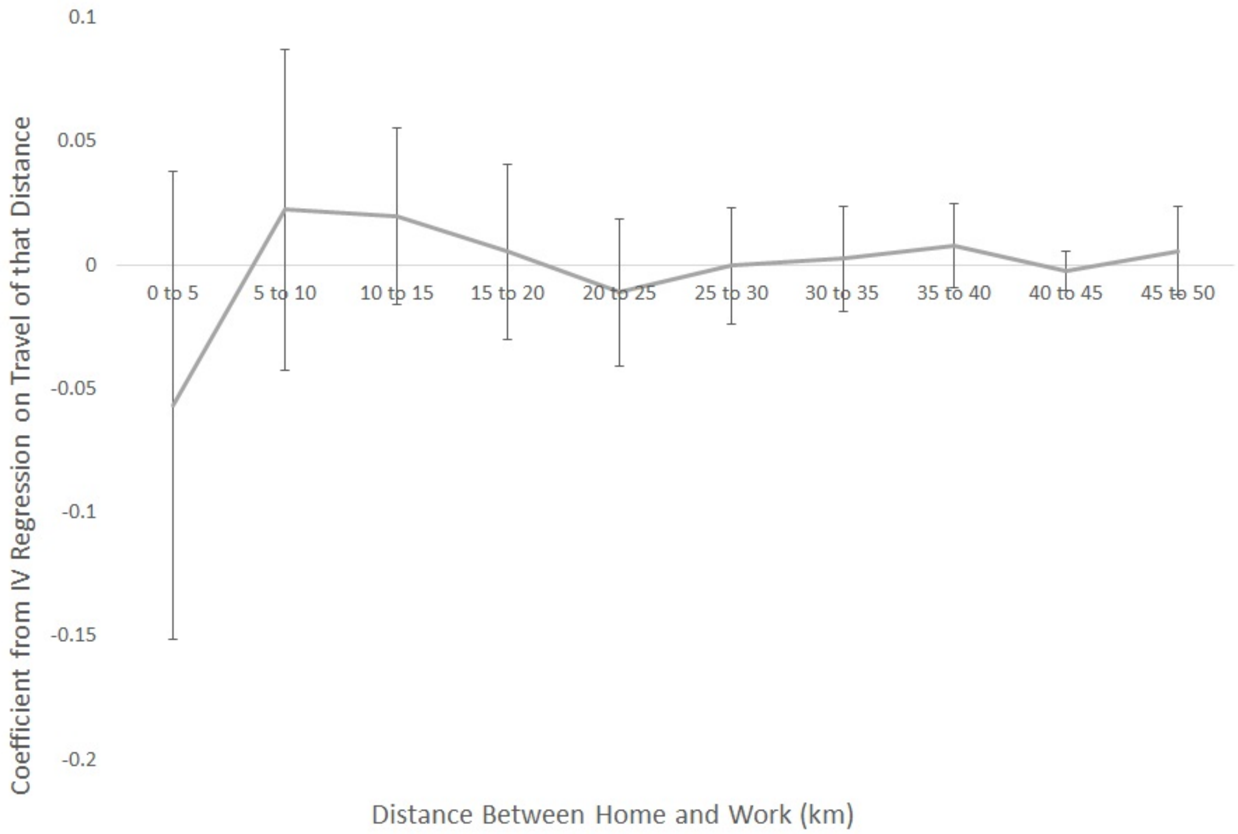
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

All regressions include fixed effects for the day of the week of the interview and the education member of the individual. Standard errors are robust and clustered at the city district level.

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 0-5km, 5-10km, etc. 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% confidence intervals on the estimate. Adding a car has no statistically distinguishable impact on the distance between home and work for any of these 5 km ranges. We do not show corresponding results for commute time for brevity, but we also do not find any



4.2 Heterogeneous Impacts

We also examine whether the number of cars had a consistent effect on travel behavior for different household types. We omit the corresponding tables from this paper for brevity, but they are available upon request.

First, we examine how the number of cars affects the travel behavior for full-time working household members of different ages. Specifically, we split our sample of full-time adults into quartiles by age and examined summary statistics and IV regressions on these subsamples.

No group has a statistically significant increase in total distance traveled, affirming the narrative we have explained above. The youngest quartile (those under age 30) have the highest amount of daily travel. When they obtain a new car, their travel shifts the most drastically, with the largest increases in driving and the biggest substitutions away from public transportation and walking. The oldest quartile (those aged 48 and above) have the least amount of daily travel. Changes in their transportation patterns are still statistically significant, but smallest when they obtain a car. The effects of new cars on travel behavior are strongest among the young.

Second, we examine how the number of cars affected travel behavior for households in different areas of Beijing. Beijing's 16 districts can be divided into four types. Ordered by their distance from the center of Beijing, the four types are: the central districts, the inner districts, the outer districts, and the suburbs. We split our sample of working adults into subsamples based on the location of the household, and examined summary statistics and IV regressions of these subsamples.

Again we find that no group has a statistically significant increase in total distance traveled. Households in central districts have the lowest amount of overall travel, and changes in their driving patterns are smallest when they obtain a car. Households in each of the other district types also increase distance traveled by car, with districts that are farther away changing their driving patterns the most when a car is obtained.

5 Implications

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

The first 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 discernable effect on the time cost of commuting to work. The introduction noted that the literature has suggested 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.

The second 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 proportional to vehicle ownership. Thus, projecting fuel consumption and pollution emissions depend largely on projecting vehicle ownership, which has received very little attention in the literature.

Third, we can estimate the effect of car ownership on total car use in Beijing to show that the lottery itself has had a large direct effect on the overall car use in Beijing. 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 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 4,735 cars removed from the road. The full BTRC sample (which includes non-participants) has 19,217 cars among those surveyed. Assuming that this survey is representative of Beijing and employing the second assumption that non-participants 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 19.8 percent.

We estimate the VKT reduction in Beijing through similar methods. According to IV estimates of equation 1, adding a car increases VKT by 7.7 km per person. Therefore, if the lottery had not existed, VKT would have been 0.65 cars*7.7 km = 5.1 km higher per person. Because losing members comprised 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.[6]

[6] We 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: those people who wish to purchase a car.

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