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# The Welfare Cost of Beijing's Lottery Policy—Evidence from a Contingent Valuation Survey

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# Abstract

Motivated by traffic congestion and air pollution, Beijing is one of several major cities to restrict vehicle ownership. Beijing residents who want to obtain a car must first win a lottery.  We examine the welfare cost of preventing people from owning cars using a new survey of Beijing lottery participants that we designed and conducted explicitly for this purpose. We find that restricting vehicle ownership reduced private welfare by 26 billion yuan. Back-of-the-envelope calculations suggest that the benefits of lower congestion and pollution roughly equal the costs. Our WTP estimates indicate a net welfare gain of about 20 billion yuan from replacing Beijing's lottery with an auction, which is smaller than the gains estimated previously in the literature.

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# 1. Introduction

China's large cities are notorious for their dense congestion, with the capital city of Beijing among the very worst in the world. In 2018 in Beijing, drivers spent about half their travel time in traffic jams during peak travel hours (Beijing Transport Research Center, 2020); overall congestion costs may amount to 12% of average income in Beijing, the highest for any city in China (AutoNavi Traffic, 2018).

To reduce road congestion and improve air quality, the Beijing municipal government restricted car ownership beginning in 2011. Under this policy, individuals who want to buy a car must first participate in a lottery. License plates were awarded only to lottery winners (Yang et al. 2014).

Beijing's vehicle ownership restrictions (VOR) have sharply reduced private car ownership and driving. The Beijing Transportation Commission found that the number of private vehicles grew by 723,000 in 2010, an increase of 23% over the prior year. Between 2014 and 2018, only 500,000 cars were added, an average annual growth rate below 3% (Beijing Transportation Research Center, 2020). Yang et al. (2020a) used the quasi-experimental nature of the lottery to estimate that it reduced the number of cars in Beijing by about 14% and miles traveled by car by 15%.

The lottery has also affected congestion and income. As we discuss in more detail later, prior to the lottery, congestion in Beijing had been steadily worsening; afterward, congestion has held steady at a lower level than it had been before the lottery's beginning. Moreover, Liu et al. (2020) find that the lottery reduced female employment as well as household income among low-income households.

Although much of the previous VOR research considers the behavioral responses to the policy, in this paper, we examine the welfare costs. Relative to a counterfactual without a lottery, the lottery imposes two costs on participants. First, it reduces welfare by preventing individuals from owning cars. Second, it misallocates cars among winners and losers. Because winning is random, some individuals with low willingness to pay (WTP) are able to obtain cars, and other individuals with high WTP are not. Estimating both components of the welfare costs requires estimates of WTP of Beijing residents for new cars.

We estimate WTP and lottery welfare costs using a new survey of Beijing lottery participants that we designed and conducted explicitly for this purpose. To elicit WTP, we administer household micro-questionnaires to lottery participants about a hypothetical Beijing license plate auction market and obtain contingent valuation method (CVM) responses of each entrant's WTP for license plates.

Among losers, the average WTP for a new car is 10,000 yuan (about $1,500 USD). In 2016, 2.6 million participants did not win the lottery, so this WTP estimate implies that the lottery has reduced private welfare by 26 billion yuan, compared to a counterfactual of no lottery. To our knowledge, this is the first estimate of the welfare costs of restricting vehicles through the lottery.

We also compare the lottery with a hypothetical auction similar to Shanghai's. Relative to an auction, a lottery has three effects on welfare. First, lottery losers with high WTP will obtain license plates. Second, lottery winners with low WTP will lose plates. Third, the auction generates revenue for the government. Our WTP estimates indicate a net welfare gain of about 20 billion yuan from replacing Beijing's lottery with an auction.

Putting our results together, the lottery imposed a welfare cost of 26 billion yuan relative to no lottery and 20 billion yuan relative to an auction. For context, we present back-of-the-envelope estimates of the benefits from lower traffic congestion, pollution, and other factors. We calculate benefits that are roughly the same as these costs.

Our estimate is the first comparison of welfare in the change from a lottery to an auction using CVM methods. Prior estimates were accomplished using revealed preference methods. Li (2018) estimates the WTP for license plates by using a structural model of the new car market and estimating demand parameters from vehicle purchase data. His result is that welfare in Beijing would have been higher by 36 billion yuan if it had an auction instead of a lottery (this estimate does not include the 21 billion yuan in fiscal revenue from the auction). As we discuss in Section 4, the difference between his estimate and ours is consistent with the literature comparing CVM and revealed preference methods. Wang and Li (2016) estimate the possible social welfare levels of Beijing, Shanghai, Tianjin, and Nanjing under three modes of license plate distribution: auction, lottery, and a mix of the two. They calculate the welfare-maximizing license plate quota under each mode and find that the net social welfare gain of replacing Beijing's lottery with an auction equal to 31 billion yuan in 2012.

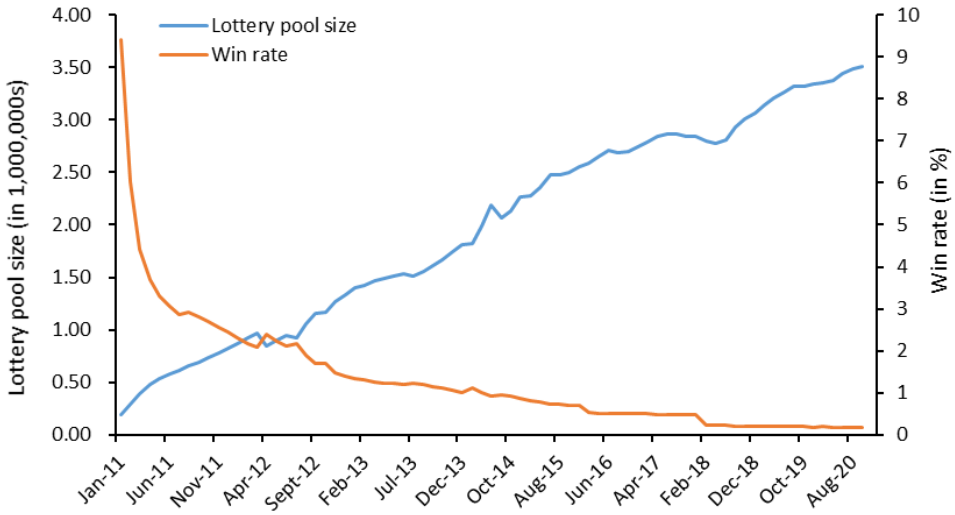
Our estimates of the welfare costs of the Beijing lottery contribute to the growing literature on the effects of vehicle ownership restrictions. Yang et al. (2014) provide an overview of some of the issues in Beijing. Li (2018) compares the welfare cost of restricting vehicles through an auction rather than a lottery. Yang et al. (2020a) examine the effects of restricting vehicles on travel behavior. Liu et al. (2020) study how eliminating vehicles can affect labor supply, finding that women who are prevented from purchasing cars have lower labor force participation rates. In contrast to these papers, our work estimates the total welfare costs to Beijing households that the lottery prevents from obtaining cars.

Our work should also be of interest to policymakers considering regulations to protect the environment. Many cities in developing countries struggle under the same sets of problems as Beijing, including congestion and air pollution. Our work compares some of the costs and benefits of restricting vehicle ownership, one possible approach to addressing these problems.

# 2. Background and Survey Design

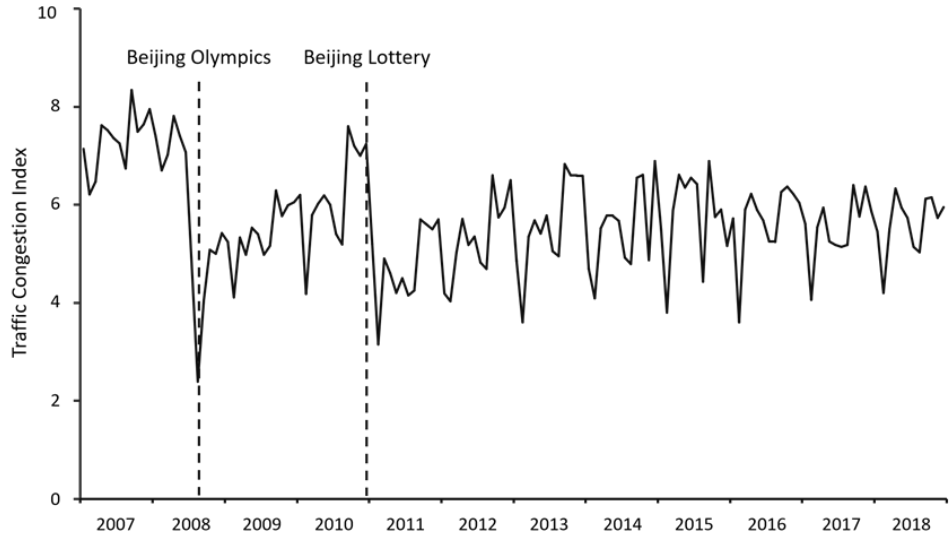
After the imposition of vehicle ownership restrictions in Beijing in 2011, the number of lottery entrants has increased rapidly, even as the number of plates awarded has remained roughly constant. Although at the advent of the lottery, only 180,000 entrants competed for 20,000 plates, 3.85 million entrants vied for about 6,000 plates per month license plates at the beginning of 2020, dropping the win rate in the lottery from 9.4% to less than 0.2% (Figure 1).

### Figure 1. The Size of the Beijing Lottery Pool and Lottery Win Rates (2011–2020)




Changes in the traffic congestion index also offer evidence on the effectiveness of these vehicle ownership restrictions. Figure 2 graphs the traffic congestion index during peak traffic hours in Beijing between 2007 and 2018. The index is a measure of average road congestion employed in China, used, for example, in Yang et al. (2018). After the implementation of the lottery policy in 2011, the average road congestion index has declined and is still lower than it was before the advent of the traffic restriction policy. Congestion also dipped temporarily around the 2008 Olympics.

**Figure 2. The Traffic Congestion Index in Beijing (2007–2018)**




In 2014, the Beijing city government commissioned a survey to better understand the transportation needs of its residents. The survey consisted of 40,000 households, drawn randomly from a complete listing of Beijing households, with the samples drawn in proportion to the population of each of the city's 16 districts. Of these 40,000 households, approximately 7,000 had at least one member who entered the vehicle lottery.

We conducted a follow-on survey on a subset of the lottery participants in the municipal survey. Our target sample is a list comprising all 764 households with at least one lottery winner and about 2,000 of the households that did not win as of the time of the initial survey. A professional survey company conducted the survey at the end of 2015 and the beginning of 2016, eventually interviewing 1,943 respondents from 677 households in Beijing.

Among these respondents, 937 said they had participated in the lottery, with 180 winners and 757 losers. The average response rate from our target sample is about 22%, and the response rates of lottery winners and losers were 21.8% and 22.2%, respectively. We find no difference in response rates between winning and losing households.

After conducting pilot interviews of Beijing households, our final survey instrument comprises two main features: a set of background characteristics and the main question on WTP. We divide the background survey into five types of questions. First, it asks respondents about their history with the lottery: which family members participated, the time of entry, and whether they won. Second, it asks them personal questions: their gender, age, years of education completed, and personal income. Third, it asks them questions about their household, including the number of members, the number of employed members, whether those members participated in the lottery, and

the number of cars owned by the household. Fourth, it asks them questions about their travel behavior, focusing on their use and access to public transportation. Finally, it asks them a few questions about their subjective attitudes toward the lottery.

The most important portion of the survey for the purposes of this study is the elicitation of WTP. The question proposes a hypothetical license plate auction designed to ask about their WTP for a license plate. The key question is the following[1]:

> *Right now, Shanghai uses an auction system to allocated license plates. If Beijing used a similar auction system, it would also give out 20,000 license plates per month. All applicants bid, and the 20,000 bidders with the highest bids will obtain license plates (note: this money is only a fee for the license plate and would not be counted as part of the purchase price of the car). However, the final price of the license plate is determined by the price of the 20,000th-highest bidder; that is to say, no matter how high the price offered by the previous bidder, the price of the license plate the 20,000 people will eventually pay is the bid of the 20,000th-highest bidder.*
>
> *For malicious bidders who offer high bids but do not purchase a license plate at the end, the license plate agency will eliminate their bids and permanently prohibit them from participating in the auction of vehicle license plates.*
>
> *Let's take a simple example to illustrate this auction rule. Suppose that 100 people participate in the auction of license plates, and 20 people will eventually get license plates. The final bidding result is 1 person's bid is 10 yuan, 18 people's bid is 7 yuan, 1 person's bid is 6 yuan, 1 person's bid is 4 yuan, and the bid of the other 79 people is 2 yuan. In our example, the final bid winner paid the license auction price of 6 yuan. All those who bid more than 6 yuan will eventually only need to pay 6 yuan to get a license plate, and those who bid less than 6 yuan will not pay any money, but they cannot get a license plate, either.*
>
> *It should be noted that the odds of winning the most recent Beijing lottery have reached 1 in 179. When making a decision, please consider this question as a real situation. If you were really asked to bid for license plates, how would you make the decision? Please answer this question as truthfully as possible; your answer is very important to our research. There is no right or wrong answer.*
>
> *Now that there is such an opportunity to bid for a license plate, how much are you willing to bid for a license plate?*

The second-to-last paragraph follows the design of Carlsson et al. (2012, 2013) and Blackman et al. (2020). It is put in place to reduce Cheap Talk and elicit the respondent's WTP to the extent possible.

1 Only an English translation of the survey question is printed here. The actual survey question was asked in Chinese and is available in the appendix.

Since our data are drawn from a list of winning and losing households, we have information on who won and lost the actual license plate lottery in Beijing. Reasoning that some households might have lower WTP for a second license plate than the first, we modified the last question in households where a lottery winner was present after the first survey as follows:

> *Supposing that nobody in your family had won the license plate lottery, how much would you be willing to bid for a license plate?*

We then held up a payment card, with a variety of ranges on it. We designed these ranges after our pilot tests of the survey. The card showed 26 WTP intervals, ranging from "1–5,000 yuan" to "125,001–130,000 yuan." The respondent could also elect not to pay or tell the interviewer that they are willing to pay an open-ended amount greater than 130,000 yuan.

Our survey is the first to ask actual lottery entrants in Beijing their WTP for license plates. We received more than 900 responses, enough to elucidate a demand curve for license plates. We saw similar response rates from winning and losing households and no observable difference between winners and losers, suggesting that the randomization of the lottery is preserved in our sample.

# 3. Summary Statistics

In theory, a randomized lottery should result in matched observable and unobservable characteristics between winners and losers. We examine the observable characteristics of survey respondents who entered the lottery in Table 1. We find that winners and losers are balanced in the set of observable characteristics that should not be affected by the lottery. They have statistically indistinguishable gender, age, marriage status, and education levels and similar family characteristics, as we see in their family sizes, the number of employed people in those families, and the number of lottery participants. They have statistically indistinguishable family incomes.[2]

The only characteristic where winners and losers are different is the number of cars they own. This is consistent with the fact that winning the lottery is a strong predictor for car ownership but that the randomized drawing allows for statistically indistinguishable characteristics for winners and losers. The similarity between winners and losers indicates that response rates did not vary with their observable characteristics, which supports the quality of the survey implementation.

We next describe our results for the key outcome variable of WTP for a Beijing license plate. We find that 57% of respondents responded that they had a 0 value for WTP. In other words, more than half said that they would be unwilling to spend any money to receive a license plate immediately.

While it may seem contradictory that entrants would wait years to win the lottery and also be unwilling to pay anything to immediately obtain a license plate, it is common in the literature for respondents to give a high proportion of zero responses in CVM WTP surveys (e.g., Jorgensen et al. 1999, Strazzera et al. 2003). This is a form of protest, where respondents object to the proposed policy change and modify their bids as a result (Morrison et al. 2000). For example, Bernath and Roschewitz (2008) investigate whether people are willing to pay to visit urban forest parks and find a zero response rate as high as 35%. Kuo and Jou (2017) find that 29.9%–44.8% of passengers were unwilling to pay extra to upgrade to a premium economy class. A survey conducted by Kwak et al. (2013) on residents' WTP for water quality finds that up to 71.8% were unwilling to pay extra to improve the quality of their tap water.

2 Liu et al. (2020) examine the effect of winning the lottery on the employment and incomes of lottery winners and losers. Using an 8,000-person survey, they also find that the average employment and incomes of winners and losers are statistically identical. However, they find that winning the lottery improves the employment rate of women without children and increases the household income for some low-income individuals.

## Table 1. Comparability of Winners and Losers

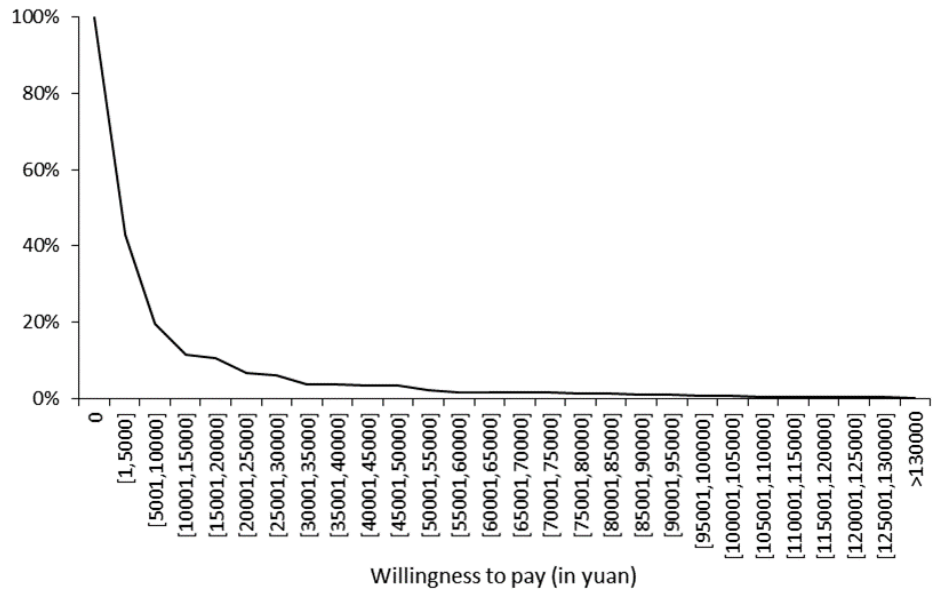
| Characteristic | Winners | Losers | Difference |
|---|---|---|---|
| Gender (male = 1) | 0.60 | 0.57 | 0.03 |
| | (0.49) | (0.50) | (0.04) |
| Birth Year | 1974.40 | 1975.66 | -1.26 |
| | (11.37) | (11.33) | (0.94) |
| Marital Status (married = 1) | 0.87 | 0.83 | 0.04 |
| | (0.33) | (0.37) | (0.03) |
| Years of Education | 13.56 | 13.76 | -0.20 |
| | (2.72) | (2.62) | (0.22) |
| Family Size | 3.01 | 2.94 | 0.07 |
| | (0.97) | (0.83) | (0.08) |
| Number of Employed Persons | 1.73 | 1.75 | -0.02 |
| | (0.91) | (0.83) | (0.07) |
| Number of Lottery Participants | 1.58 | 1.62 | -0.04 |
| | (0.68) | (0.64) | (0.05) |
| Personal Income (RMB) | 54,305 | 58,673 | -4,367 |
| | (3,704) | (2,180) | (4,935) |
| Family Income (RMB) | 62,087 | 70,789 | -8,703 |
| | (4,931) | (2,427) | (5,527) |
| Number of Cars | 1.21 | 0.48 | 0.72*** |
| | (0.44) | (0.65) | (0.04) |
| N | 180 | 757 | 937 |

Notes: The first two columns report the means of each characteristic for lottery winners and losers with standard deviations in parentheses. The third column reports the difference between winners and losers with standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Meyerhoff and Liebe (2010) analyze the determinants of protest responses in environmental valuation studies. Among the 157 papers included, the average probability of a protest response was about 18%. They find that open-ended WTP questions are associated with more protest responses. Respondents also offered more protest responses when faced with a surcharge for an existing service. Additionally, some evidence suggests that the setting of the question is an important factor, with higher WTP responses recorded in Scandinavian countries where incomes and trust in the government are high. All of these factors are potentially important in our setting. Importantly, 87% of the respondents in our sample said that they favor Beijing's current method of randomly assigning license plates.

Restricting our sample to those whose WTP is not 0, 23.5% chose the WTP interval 1–5,000 yuan and 8.1% chose 5,001–10,000 yuan. Every other interval has a frequency below 5%. The maximum WTP value was 200,000 yuan. Figure 3 shows the cumulative distribution of respondents' WTP for license plates. Since about 90% of respondents' WTP is less than RMB 10,000, this curve has a clear long-tail distribution.

## Figure 3. Cumulative Distribution of WTP Responses for a License Plate in Beijing




In the following analyses of WTP, we use the average of the ends of each interval range as the respondent's WTP. For example, if the respondent stated a WTP in the range of 1–5,000 yuan, we impute the WTP as 2,500 yuan. If the respondent selected 0 or specifies a WTP beyond 130,000 yuan, we use the value given by the interviewee as the WTP.

Table 2 compares the average WTP of lottery winners and losers, which was 10,125 yuan and 4,333 yuan, respectively. The difference between the two is large and statistically significant. We next examine the number of respondents with a WTP of 0. Lottery winners and losers have a 58.9% and 56.5% chance of reporting 0, respectively; the difference between these two fractions is statistically insignificant. The difference in WTP must stem from responses from each group with nonzero WTP; we affirm a large and statistically significant difference (14,659 yuan) between these responses.

## Table 2. Comparison of WTP of Lottery Winners and Losers

| | Winners | Losers | Difference |
|---|---|---|---|
| WTP (yuan) | 10,125 | 4,333 | 5,792*** |
| | (26,155) | (12,448) | (2,001) |
| Fraction of zero WTP respondents | 0.589 | 0.565 | 0.023 |
| | (0.493) | (0.496) | (0.041) |
| WTP for respondents with nonzero WTP (yuan) | 24,628 | 9,970 | 14,659*** |
| | (36,268) | (17,342) | (4,323) |
| N | 180 | 757 | |

Notes: The first two columns report the means of each characteristic for lottery winners and losers with standard deviations in parentheses. The third column reports the difference between winners and losers with standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Respondents' subjective attitudes toward transportation policies may also affect their WTP. Table 3 reports WTP according to respondents' stated attitudes toward their own luck and the lottery. Respondents who think they have good luck in the lottery have a higher WTP than other respondents. About 81% of lottery winners think they are lucky, whereas only 2% of lottery losers think they are lucky; this implies that the lottery outcome is an important factor affecting respondents' subjective evaluations of their own luck.

Respondents' perceptions about the fairness of the lottery, their preference VOR, and their beliefs about the effectiveness of VOR are not associated with a difference in WTP. However, the WTP of respondents who prefer Shanghai's license plate auction policy is significantly higher than those who prefer Beijing's license plate lottery policy; the difference is large and statistically significant. This suggests that respondents who would prefer a different mechanism for allocating vehicle license plates also have higher WTP for those license plates.

## Table 3. WTP Analysis, by Attitudes of Respondent

| | | Average WTP (yuan) | Fraction of zero WTP respondents | WTP for respondents with nonzero WTP (yuan) |
|---|---|---|---|---|
| Evaluation of own luck in the lottery | Lucky | 9,402 | 0.558 | 21,285 |
| | (N = 163) | (24,688) | (0.498) | (33,677) |
| | Not lucky | 4,612 | 0.572 | 10,786 |
| | (N = 744) | (13,584) | (0.495) | (19,118) |
| | Difference | 4,789** | 0.014 | 10,499 |
| | | (1,994) | (0.043) | (4,106) |
| Whether the lottery is fair | Fair | 6,350 | 0.558 | 14,359 |
| | (N = 450) | (16,132) | (0.497) | (21,784) |
| | Not fair | 4,610 | 0.581 | 11,005 |
| | (N = 487) | (16,160) | (0.494) | (23,547) |
| | Difference | 1,740 | 0.023 | 3,354 |
| | | (1,056) | (0.032) | (2,259) |
| Preference for lottery | Prefer lottery | 3,192 | 0.622 | 8,439 |
| | (N = 817) | (9,674) | (0.485) | (14,265) |
| | Prefer auction | 20,792 | 0.217 | 26,543 |
| | (N = 120) | (33,769) | (0.414) | (36,123) |
| | Difference | -17,600*** | 0.405*** | -18,104 |
| | | (3,101) | (0.041) | (3,813) |
| Preference for vehicle ownership restrictions (VOR) | Support VOR | 5,200 | 0.584 | 12,485 |
| | (N = 802) | (16,291) | (0.493) | (23,392) |
| | Do not support | 6,907 | 0.489 | 13,514 |
| | (N = 135) | (15,342) | (0.502) | (19,319) |
| | Difference | -1,708 | 0.095** | 1,029 |
| | | (1,503) | (0.047) | (2,655) |
| Evaluation of the effectiveness of VOR | Effective | 5,951 | 0.542 | 12,983 |
| | (N = 384) | (19,122) | (0.499) | (26,616) |
| | Ineffective | 5,095 | 0.590 | 12,412 |
| | (N = 553) | (13,743) | (0.492) | (19,239) |
| | Difference | 856 | -0.048 | 571 |
| | | (1,074) | (0.033) | (2,378) |

Notes: The first two columns report the means of each characteristic for lottery winners and losers with standard deviations in parentheses. The third column reports the difference between winners and losers with standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.10.

Based on this analysis, the key factors correlating with higher WTP among lottery entrants are the lottery outcome and whether the entrant supported an auction rather than a lottery. Winners may have higher WTP because they are able to enjoy the benefits of driving and so have a higher WTP for license plates. Additionally, the welfare cost from losing a personal possession may be higher than the gain from obtaining a new possession. Individuals who support the auction format may have higher WTP because they know they would be able to obtain a license plate under the auction system that they are denied under the lottery system.

In summary, we find significant difference in WTP for a license plate among the respondents. Potential reasons include whether winning the lottery and a sets of subjective attitudes toward transportation policy. Therefore, in the next section, we use a simple econometric model to analyze factors affecting whether respondents are willing to pay a certain amount for obtaining license plates and how much they are willing to pay.

# 4. Econometric Model and Empirical Results

## 4.1. Empirical Analysis

The objective of our empirical analysis is using the survey responses to estimate WTP for owning a car. This estimate depends on how we handle the high proportion of respondents who reported zero WTP, which we discuss here.

Some studies eliminate these respondents or replace them with a small positive value. However, dropping them eliminates valid sample information and can cause sample selection bias (Brouwer and Martín-Ortega, 2012). Using a small positive value to replace the zero responses lacks a theoretical basis and is subjective. Some studies use special estimation methods, such as the tobit model, to analyze censored data (Halstead et al., 1991; Carlsson et al., 2012). However, the tobit model allows only one type of zero observation: a zero value arising as a result of the respondent's economic circumstances. This model is ineffective if some respondents consider the good to negatively affect welfare (Martínez-Espiñeira, 2006), as might be the case for Beijing citizens who strongly favor the existing lottery allocation mechanism over the auction mechanism.

As an extension of the tobit model, Cragg (1971) proposes a hurdle model for processing censored data. According to this model, consumer behavior can be decomposed into two decisionmaking processes: first, the individual decides whether to enter the market for a product; second, the individual decides how much to pay for that product.

Correspondingly, our empirical strategy is divided into two parts. First, we use the full sample in a probit binary selection model where the dependent variable is a positive WTP. Second, we restrict the sample to respondents with positive WTP to study participants' factors contributing to their WTP values.

The explanatory variables used in each part of the model are the same. These respondent variables can be divided into four types: (1) Individual characteristics, including gender, age, education level, personal annual income, and whether they have won the lottery; (2) family characteristics, including the number of household members, number of working members, number of members participating in the lottery, and household car ownership; (3) travel behaviors, including the total number of bus and subway trips each week and walking from home to the nearest station; (4) subjective attitudes, such as their opinion on the fairness of lottery, preference for lottery and auction policies, and views on VOR.

| Variables | | Probit | OLS |
|---|---|---|---|
| Individual Characteristics | Gender (male = 1) | -0.029 | 0.624 |
| | | (0.034) | (2.267) |
| | Years of Education | -0.001 | 0.002 |
| | | (0.002) | (0.131) |
| | Whether the Person Won the Lottery | 0.024** | 0.454 |
| | | (0.010) | (0.471) |
| | Years of Education | 0.001*** | 0.042 |
| | | (0.001) | (0.061) |
| | Family Size | -0.032 | 13.379** |
| | | (0.052) | (5.944) |
| Household Characteristics | Number of Household Members | -0.035 | 0.720 |
| | | (0.031) | (1.921) |
| | Number of Working Household Members | -0.007 | -0.983 |
| | | (0.037) | (2.439) |
| | Household Members Participating in Lottery | 0.017 | 2.667 |
| | | (0.037) | (2.465) |
| | Number of Cars | -0.016 | 0.782 |
| | | (0.038) | (2.373) |
| Travel Behavior Characteristics | Weekly Number of Trips via Public Transportation | -0.001 | -0.105 |
| | | (0.003) | (0.152) |
| | Time to Walk to the Nearest Public | -0.008* | 0.096 |
| | Transportation Station (Subway or Bus) | (0.004) | (0.267) |
| | Total Walking Time | 0.001 | -0.035 |
| | | (0.000) | (0.031) |
| Subjective Attitude Characteristics | Evaluation of Lottery Fairness (Fair = 1) | 0.059 | -2.903 |
| | | (0.044) | (4.215) |
| | Preference for License Plate Allocation | 0.377*** | 20.076*** |
| | Policy (Favors Auction = 1) | (0.059) | (5.029) |
| | Preference for Vehicle Ownership | -0.096* | 0.378 |
| | Restrictions (Favors Restrictions = 1) | (0.057) | (3.182) |
| | Evaluation of Effectiveness of Vehicle | -0.058 | 1.234 |
| | Ownership Restrictions (Effective = 1) | (0.046) | (5.554) |
| N | | 610 | 263 |
| $R^2$ | | 0.119 | 0.209 |

Notes: (1) In the probit model, the dependent variable is whether the survey respondent reported a WTP higher than 0; the marginal effect of each coefficient is reported. (2) In the OLS model, the dependent variable is WTP, in thousands of yuan, with only respondents with WTP greater than 0 included. The coefficient estimate is reported. (3) Robust standard errors clustered by household are reported in parentheses. (4) *** p < 0.01, ** p < 0.05, * p < 0.10.

Based on the probit results, we find that the most important factors correlating with an individual's willingness to participate in an auction for license plates are education, income, and attitudes toward the lottery. Respondents who favor an auction over a lottery are much more willing to participate in an auction, and those who support VOR are somewhat less likely.

We interpret the marginal effects of the statistically significant coefficients in this model as follows: each additional year of education is correlated with a 2.4 percentage point increase in participation in the auction. Each thousand yuan increase in personal income is correlated with a 0.1 percentage point increase. Preferring the auction over the lottery is correlated with a 37.7 percentage point increase. Favoring VOR is correlated with a 9.6 percentage point reduction in participation.

Based on the OLS results, we find that the only statistically significant correlates of WTP were whether the person won the lottery and whether they favored an auction or a lottery. To interpret the coefficients in this regression, we find that the WTP of lottery winners is 13,379 yuan higher than that of losers. Respondents who prefer the auction over a lottery have a 20,076 yuan higher WTP than that of other respondents. Considering that the average WTP for all respondents with positive WTP is only 12,661, these two factors have large explanatory power.

Understanding the determinants of WTP helps us understand why respondents have high and low valuations for the commodity. The finding of a very strong difference in WTP between winners and losers of the lottery implies that entrants who have experienced car ownership have a much higher value for cars.

## 4.2. The Social Cost of the Lottery Policy

In this section, we analyze the social welfare cost of Beijing's current lottery policy in two separate dimensions. First, we calculate the welfare loss to vehicle owners from the lottery policy relative to a counterfactual with no VOR. To our knowledge, we are the first to calculate this statistic. Second, we calculate the welfare loss to Beijing of using a lottery rather than an auction. Li (2018) analyzed this problem, using the method of revealed preference demand estimation.

### 4.2.1. Comparing the Lottery to a City with No Vehicle Ownership Restrictions

We begin our welfare analysis by stating the assumptions under which we perform these analyses. First, we assume that everyone who would want a car in Beijing would enter the license plate lottery. This assumption is supported by the fact that entering the lottery has no financial cost and is done with a simple, 10-question online application. Second, we assume that VOR do not affect the value of cars apart from who owns them. VOR might influence the value of cars through changes in congestion if they affect congestion in the long run (we will discuss this assumption further).

Under these assumptions, the difference in welfare caused by removing VOR is simply the sum of WTP of all lottery losers, if they had the right to purchase license plates. However, lottery losers' responses to our survey may not reflect their WTP if they had the right to purchase license plates. People who own cars and experience the stream of services a car provides are more likely to correctly value those services than people who do not own cars, as explained, for example, in Kahneman and Thaler (2006). Lottery losers thus might have a misguided internal estimation of cars' value.

To estimate losers' WTP, we start from the idea that the randomization provided by the lottery should create groups of winners and losers that have identical average observable and unobservable characteristics. Table 1 supports this claim by showing that all observable characteristics of these two populations are statistically indistinguishable. If winners and losers are separated only by random draw, then losers would have the same WTP as winners if they were given the right to purchase a car.

As of February 2016,[3] when our survey was taken, the Beijing vehicle lottery had 2.59 million entrants.[4] We assume that, in the absence of VOR, all entrants would be given the right to purchase a car and thus have the WTP of lottery winners. Since winners' average WTP (including those reporting a WTP of 0) is 10,125 yuan, we conclude that VOR decrease utility by (2.59 million people * 10,125 yuan/person) = 26.2 billion yuan.

To provide context for this cost estimate, we provide back-of-the-envelope calculations of the congestion and pollution benefits of the lottery for 2011–2016. Because the lottery reduces the number of cars on the road, lower congestion and pollution from a decreased number of cars should benefit all drivers and residents, not just those who win a car. The aggregate congestion benefits equal the change in VKT multiplied by the average cost of congestion per VKT.

Yang et al. (2020) use travel diaries of a large sample of households in Beijing to examine the distances traveled by car for lottery winners and losers. Under the assumption that the lottery outcome is random, losers would behave like winners if they had won. Losers travel by car 6.7 km per day on average; winners increase this amount by 7.9 km per day, more than doubling the travel of losers.

We apply this estimate of 7.9 km per lottery per day to the pool of lottery losers each year. For example, in 2014, 2.25 million entrants had not won. If these losers behaved like winners, VKT in Beijing would be (2.25 million * 7.9 * 365) = 6.49 billion km higher that year. Using similar calculations, we calculate that between 2011 and 2016, the

3 Statistics on the number of entrants and winners are taken from the Beijing vehicle lottery website (**https://www.bjhjyd.gov.cn/**).

4 Although the size of the pool was 2.59 million, there have been more lottery losers over the history of Beijing's lottery, because some losers were removed. The rules of this lottery require participants to periodically renew their application in order to stay in the pool. These renewals are free and can be accomplished online. As a result, we assume that lottery participants who did not renew their application have very low WTP.

lottery reduced total travel by 33.0 billion VKT.[5]

We multiply the VKT reduction by an estimate of the damages per kilometer of travel for Beijing. Following Li (2018), we rely on Creutzig and He (2009) for an estimate of the total damages from vehicle use, which includes congestion, pollution, and other external costs, such as noise pollution (congestion and pollution account for the vast majority of external costs). They estimate costs of 0.85 yuan per kilometer (2012 yuan). If we multiply this number by the VKT reduction, we find that the social benefits of restricting vehicles equal to 28.0 billion yuan. This suggests that the benefits from restricting cars in Beijing are almost the same size as the welfare costs.

As an alternative to this estimate, we can use the marginal congestion damages from Yang et al. (2020b) to obtain a lower bound of the social benefits of the lottery that does not include the noncongestion benefits. They estimate that the average congestion cost is 0.46 yuan per VKT in 2014, which is roughly the midpoint of the period we consider. This estimate implies congestion benefits of 15.2 billion yuan from 2011 through 2016.[6] If we consider a lower bound that includes only congestion benefits, these are about 58% of costs.

### 4.2.2. Comparing the Lottery to Restricting Vehicles Using an Auction

To compare the difference in social welfare between Beijing's lottery and a hypothetical auction, we first assume that the basic mechanics of the auction would be the same as the lottery now. To be specific, we assume that the same number of license plates would have been given away under each system. Under this assumption, congestion and other conditions affecting the value of license plates would be unaffected because the same number of cars would be on the road in each scenario. Second, with multiple lotteries, we assume multiple auctions. However, high WTP entrants should enter auctions before low WTP entrants, ensuring that no entrants with low WTP would obtain a license plate simply because the auction was undersubscribed.

As of February 2016, about 922,500 people had won the lottery. With 2.59 million people in the pool as of this date, this implies a cumulative win rate of 922,500 / (2.59 million + 922,500) = 26%. If vehicles were restricted through an auction, people who

5 To make this calculation, we assume that the 7.9 km is the average daily travel of losing lottery participants from 2011 to 2016. This assumption is supported by the fact that the empirical estimate is drawn from 2014 data, which is roughly the midpoint of the period.

6 The costs of the lottery depend on the WTP of owning a car. When we calculated the costs of the lottery, we assumed that the lower congestion caused by the lottery did not affect WTP. If lower congestion raised WTP, our estimate would overstate lottery costs. However, this bias might be small. Our estimate of lottery costs covers 2011–2016. Restricting vehicles would have a larger effect on congestion at the end of that period than at the beginning, because congestion tends to increase. Our survey, conducted in 2014, would use congestion levels near the midpoint of the period and would likely correspond to an average of low and high levels during the period.

have a WTP in the top 26% should receive a car, paying a market-clearing price for the license plate equal to the WTP of the person at the 74th percentile.

There are three primary differences between the total welfare when cars are distributed under an auction versus a lottery. First, lottery losers with a WTP above the 74th percentile will obtain license plates. Second, lottery winners with a WTP below the 74th percentile will lose their plates. Third, all auction winners would transfer the auction price to the government.

We analyze each of these components separately, again under the assumption that the true WTP of car owners is reflected by lottery winners; losers would have this WTP distribution if they had experienced car ownership. To analyze the WTP gain associated with losers gaining cars, we first calculate that the 74th percentile of WTP of winners is 7,500 yuan. The average WTP of winners with WTP greater than this is 29,840 yuan. Applying this average WTP yields a total WTP gain of (2.59 million * 26% * 29,840) = 20.1 billion yuan.

To analyze the WTP loss associated with lottery winners losing cars, we calculate that the average WTP of winners below the 74th percentile is 500 yuan. The welfare loss associated with these winners not obtaining cars would then be (922,500 * 74% * 500 yuan) = 341 million yuan. This figure is much smaller than the potential gain from auction winners because so many respondents listed their WTP for a license plate as 0.

To analyze the third component of the change in welfare from this policy change, we note that payments made after winning the auction are government transfers with no net welfare impact. Li (2018) also treats these transfers as welfare neutral, noting that the Shanghai government spent auction revenues on funding for public transportation infrastructure. If the funds spent on this infrastructure have a value greater than their cost, our results could understate the benefit from the lottery.

To summarize the change in welfare as a result of moving from a lottery to an auction, we calculate that allowing lottery losers to participate in the auction would result in a welfare gain of 20.1 billion yuan, whereas removing license plates from lottery winners who have low WTP would result in a loss of 341 million yuan. As a result, the net change in welfare would be (20.1 billion – 341 million) = 19.7 billion yuan. Wang and Li (2016) and Li (2018) estimate that the net social welfare loss of Beijing's lottery policy was about 30 billion yuan, about 50% larger than the social cost estimated in this paper.

We attribute this difference in results to our different methods of analysis. Our work obtains respondents' WTP using CVM, one type of stated preference tool. Li (2018) estimates WTP for license plates using actual car purchases, a revealed preference method. The assessment of welfare using these two methods is often inconsistent, even when the same individual is studied (Adamowicz et al., 1994).

Other studies have also found that CVMs result in lower WTP than revealed preference methods. Carson et al. (1996) reviews 83 studies taking place between 1966 and 1994 with stated preference and revealed preference methods. On average, stated preference methods found WTP values 89% of those from revealed preference

methods. This result is somewhat larger because of outliers; after excluding the largest 5% and smallest 5% of samples, stated preference methods found results only 77% of those from revealed preference methods. In summary, the difference between our finding using stated preference methods and the findings of previous papers using revealed preference methods is consistent with the previous literature on this topic.

To provide context for our estimated cost of VOR, we compare it to those of vehicle usage restrictions. These policies, also implemented in Beijing, restrict usage of vehicles on certain days based on the last digit of the license plate. Blackman et al. (2020) use a CVM similar to that of this paper and estimate that the social cost of Beijing's restriction policy was between 1.6 billion and 3.3 billion yuan.

Our estimates of the welfare loss to Beijing through the imposition of VOR is 26.2 billion yuan, about 10 times the estimated cost of usage restrictions. As expected, the social cost of not allowing people to purchase vehicles is much higher than restricting vehicle usage.

# 5. Conclusion

In this paper, we use CVM to ask Beijing lottery entrants their value for obtaining a license plate. Despite a large number of protest respondents reporting a WTP of 0, we find that restricting vehicle ownership has large social costs of 26.2 billion yuan. Our back-of-the-envelope calculation suggests that restricting vehicle ownership has provided social benefits in the form of reduced congestion and pollution of 28.0 billion yuan, almost the same magnitude.

Our results should be of interest to many developing countries, whose car markets have grown in size as they have become more wealthy. Many large cities in developing countries face increasingly severe traffic congestion and air pollution problems. As policy makers grapple with these problems, VOR may become a more and more popular option. This work on the Beijing vehicle lottery provides insight into one welfare cost of restricting vehicles: the lost WTP of preventing people who want to purchase cars from being able to buy one.

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# Appendix

Chinese Version of Survey Question Given to Households of Lottery Entrants in Beijing

目前上海采取拍卖制度分配车牌，假如北京也采用类似的拍卖制度分配车牌，在这种新机制下，假定每个月的车牌总数为20000个。所有申请者进行投标，出价最高的20000个竞标者能够获得车牌（注意：这个钱仅仅是车牌拍卖费，并不算作购车款的一部分）。但车牌的最终价格由出价排在最后一位的第20000个竞标者的价格决定；也就是说，无论前面的竞标者出的价格多高，这20000个人最终需要支付的车牌价格是第20000个竞标者出的价格。

但是，对于那些出高价但最后不同意支付拍卖费用的恶意竞拍者，牌照拍卖组织机构将其竞价废除，并永久禁止其参与车辆牌照的拍卖。

我们举个简单的例说明这个拍卖规则，现假定有100人参与车牌拍卖竞价，最终将有20人获得车牌。最终竞标结果是：1人的竞价是10元，18人的竞价都为7元，1人的竞价是6元，1人的竞价是4元，其他79人的竞价都为2元。在我们这个例子中，最终竞标胜出者支付的牌照拍卖价格为6元。所有出价高于6元的人最终只需支付6元，即可获得车牌；而那些出价低于6元的人不支付任何钱，但也不能获得车牌。需要说明的是，目前最新的北京市摇号中签率已达到179:1。在做决定的时候，请把这个问题当作真实的情况来考虑，如果真的让您去竞标拍卖车牌，您会怎么做决定。