The Distributional Effects of Lotteries and Auctions

—License Plate Regulations in Guangzhou

Abstract

Lotteries and auctions are common ways of allocating public resources, but they have rarely been used simultaneously in urban transportation policies. This paper presents a unique policy experiment in Guangzhou, China, where lotteries and auctions are used in conjunction to allocate vehicle licenses. Guangzhou introduced vehicle license regulations to control the monthly quota of local automobile growth in 2012. To obtain a license, residents are required to choose between the lottery and auction method. Since the introduction of the regulations, there has been heated debates on the distributional effects of lotteries and auctions; however, the debates have not been grounded in empirical studies. We analyze the distributional effects of such mixed mode of resource allocation in a positive manner based on individual behavioral choices. We conducted a survey in January 2016 (n = 1,000 people * 12 months), and used mixed logit models to analyze how socio-economic status, including income and automobile ownership, determined people's choices among lottery, auction, and non-participation alternatives. We find that income increased participation, but did not influence non-car owners' choices between lotteries and auctions, which contrasts with the common notion that lotteries benefit the poor. Additionally, the positive impact of car ownership on participation indicates a car-dependent trajectory for automobile growth. The significant socio-economic differentiators between lotteries and auctions were age, gender, and education. Proxies of mobility needs were insignificant overall. The program attributes had a much larger impact than all other variables—people were more likely to choose lotteries with higher winning rates and more participants and more likely to choose auctions with higher prices and more participants. We concluded that for those who participated, the choice between lotteries and auctions did not depend on their income or mobility needs but, rather, the probability of winning plates and the opportunity for speculation.

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Key Words: automobile regulation; distributional effect; lottery; auction; mixed logit model

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Introduction

The transitional economy in China has significantly increased the number of individuals purchasing personal automobiles. Between 2000 and 2014, the total number of passenger car owners in China grew from 16.1 to 146 million (National Bureau of Statistics of China, 2015). This rapid growth has led to severe problems including air pollution, congestion, and energy consumption. Motor vehicles consume approximately 50% of the total oil consumed annually in China (Davis, Diegel, & Boundy, 2008; Ma, Fu, Li, & Liu, 2012). To mitigate this unprecedented growth, Chinese local governments, including those of Beijing, Shanghai, Guangzhou, and four other major cities have implemented a series of license plate regulations. Beijing and Shanghai allocate car license plates by lottery and auction, respectively. In 2012, the Guangzhou government implemented license plate regulation characterized by its mixed allocation mode. Of the total license plates allocated, 50% were through lotteries, 40% through auctions, and 10% were assigned to new-energy vehicles. This study is fueled by the discussions on the distributional effects of lotteries and auctions, which have been heatedly debated by scholars and the public since the regulations were introduced. For example, although, theoretically, auctions are the most efficient way to allocate public resources, their use has been opposed by many who contend that auctions can harm the poor because the poor do not have the economic power to win license plates in such stiff competition (Xue, 2004; Ye, 2007). In contrast, others argue that auctions respect different levels of mobility needs and can yield revenues that are, in turn, invested in public transit to subsidize the poor (Fan, 2013; Nie, 2013).

This study analyzes the distributional effects by surveying how people behave under the mixed allocation rule in Guangzhou. In particular, we are interested in how socio-demographic variables, such as income and automobile ownership, determine the choices among lottery, auction, and non-participation alternatives. Although the distributional effects of lotteries and auctions have been debated extensively in China, no past study has grounded its argument in solid empirical evidence. One critical reason is that there is no publicly available dataset that provides individual-level information. This study responds to this gap by drawing on results from a survey we conducted in January 2016, which captures the choice behaviors of 1,000 Guangzhou residents in each of the months in 2015 during which they participated (up to 12 months). To elicit individual behaviors, we asked survey respondents to report their choices among lottery, auction, and non-participation alternatives in each month between January and December 2015. The survey included questions related to residents' income, socio-demographics, and travel information, which are the potential determinants of residents' choices. The dataset at the individual level allows us to analyze exactly how each resident behaved when faced with the choice between lottery, auction, and non-participation alternatives.

Beyond the application to license plate regulations, lotteries and auctions are generic ways to allocate limited public resources. Traditionally, scholars believe that lotteries benefit the poor while auctions benefit the rich (Sandel, 2010). However, the empirical evidence is rare for situations where lotteries and auctions are simultaneously employed. None of the cases have produced individual-level behavioral data. Therefore, the

Guangzhou policy provides a rare opportunity to illustrate the tradeoff between lotteries and auctions in one single policy.

We choose Guangzhou as an exemplary case illustrating the license plate regulations in China. Figure 1 shows that Shanghai was the first to limit license plate registration in 1994. After 16 years, Beijing implemented its own license plate regulation. The two policies are similar as both restrict automobile ownership growth; however, they differ in that Shanghai holds auctions to allocate license plates while Beijing conducts lotteries. In 2012, Guangzhou introduced its policy characterized by its mixed allocation rule. The evolution of the series of license plate regulations has shown that the mixed mode is becoming increasingly influential because several cities have adopted this mode emulating Guangzhou. As the first city to use the mixed mode, Guangzhou deserves close examination. In Guangzhou, each month, residents can obtain a license plate by choosing between a lottery and an auction, but they cannot choose both. Individuals can re-enter the process every month or choose to drop out. Once a person wins a license plate, they must register an automobile with the license plate within six months. The winner is not allowed to trade the license plate. The public dataset published by the Guangzhou government provides the total number of entrants in lotteries and auctions but not individual-level data. The published dataset shows that overall, people preferred lotteries to auctions. For example, in December 2015, the quota of the plates auctioned was 3,550, and the quota allocated by lottery was 4,840. However, in the same month, there were 12,804 auction participants and 415,644 lottery participants. Given the low winning rates of lotteries, auctions are a quick means of obtaining a license plate. In fact, this pattern of high winning rates of auctions and low winning rates of lotteries has been quite consistent since the beginning of this policy, as shown by the Graph d in Figure 2. Figure 2 shows how the numbers of entrants, quota, winning rates, and prices evolved during the past 36 months from 2013 to 2015. For the detailed mechanisms of this Guangzhou policy, please read the Appendix.

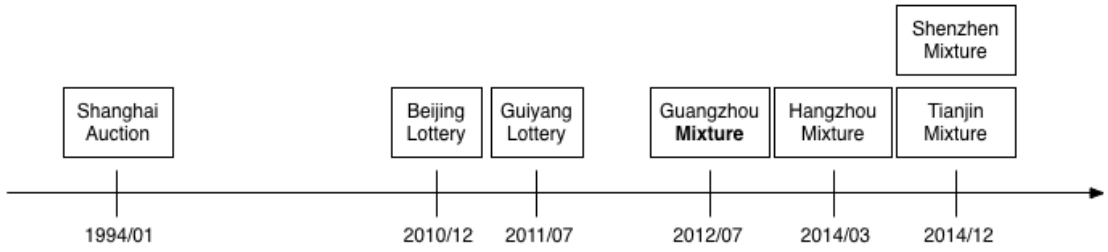

Figure 1 Evolution of license plate regulations in China

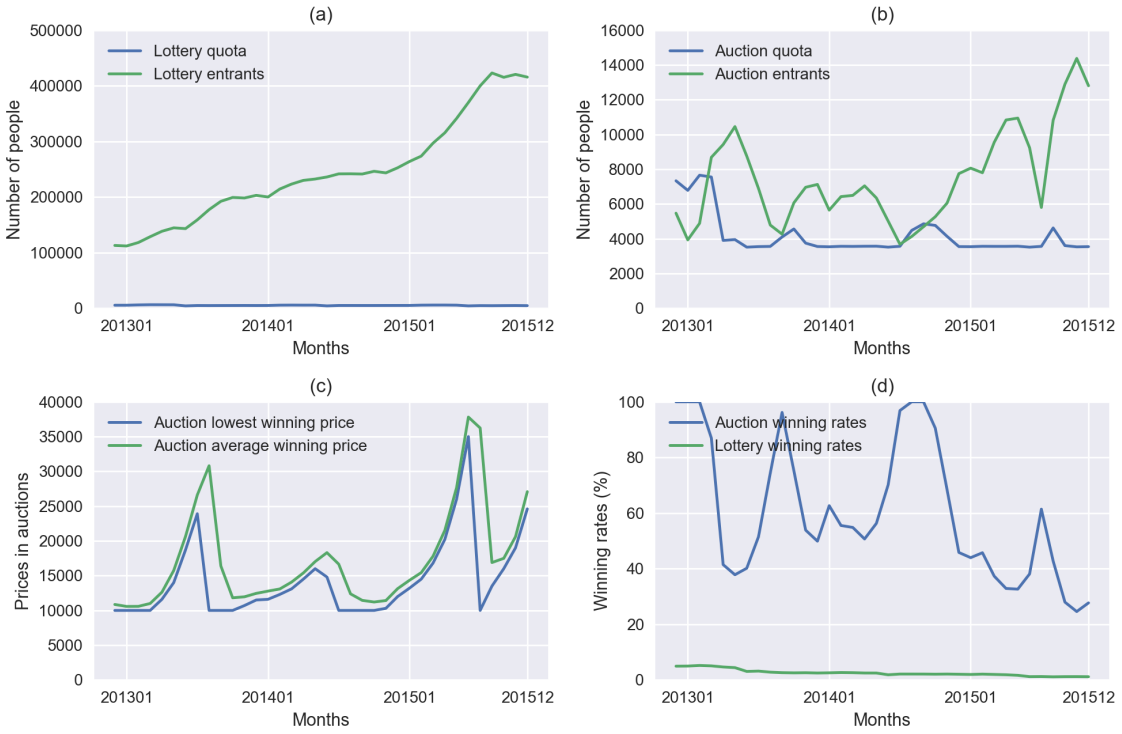

Figure 2 (a) lottery quota and entrants; (b) auction quota and entrants; (c) prices in auctions; (d) winning rates of lotteries and auctions

The following section reviews the literature on lotteries and auctions and the Guangzhou case. The data collection and analytic method section introduces the survey, the key statistics and the specification of the models. Subsequently, we estimate and compare a multinomial logit model and a mixed logit model and discuss their limitations. The final section summarizes our findings and concludes.

Literature Review

Lotteries and auctions are two common ways to allocate public resources such as health care, public housing, and recreational opportunities. Lotteries are often considered fair while auctions are perceived as efficient but unfair (Evans, Vossler, & Flores, 2009; Goodwin, 2013; Hofstee, 1990). Taylor, Tsui, & Zhu (2003) argue that a lottery is "usually employed to resolve allocation problems to reflect a spirit of fairness and equality, since everyone has an equal chance to win, regardless of whatever characteristics or qualities one may possess." Sandel (2010) argues that it is fair, particularly between the rich and the poor, to conscript people into the army through lotteries; however, the option of buying out after the lottery renders the process unfair because the poor are destined to be conscripted into the army.

Proponents of auctions often ground their argument in social welfare or efficiency (Cheung, 1974; Evans et al., 2009). Competition does not disappear after any price or quantity control but only takes different forms, such as waiting in queues, competing based on friendship or physical violence, or using power in a black market (Cheung, 1974). Rationing by lotteries causes rent dissipation, which is a waste of social resources

(Cheung, 1974). Similarly, Barzel (1974) suggests that rationing properties by lottery is costly because competitors need to "bid" by waiting; however, the waiting time spent on queues is not transferable leading to huge losses for society. Xue (2012) makes an outright claim that rationing public resources without a price is the most wasteful of all allocation methods.

Considering the pros and cons of lotteries and auctions, a mix of these two allocation mechanisms has been increasingly implemented by governments and discussed by scholars. Evans et al. (2009) provide an example in which the permits for passing through the Panama Canal are allocated by a mix of lotteries and auctions. In relation to immigration policies, auctions are proposed as a complement to current lotteries to allocate specialty worker visas (Committee for Economic Development, 2001). Evans et al. (2009) discuss the theoretical impact of mixing lotteries and auctions without any empirical support. The authors conclude that auction bids can be systematically reduced because lotteries function as an opportunity cost of auctions, and a mixed allocation mechanism does not compromise the efficiency of its auction component.

Similar to the generic theoretical view, Chinese scholars primarily believe that lotteries are fair and auctions are unfair license plate regulation methods. After auctions had been implemented in Shanghai, scholars critiqued that the auctions only benefitted the rich to the detriment of the poor (Xue, 2004; Ye, 2007). This argument is appealing since the price of a license plate in Shanghai's auction has been over CNY 84,000 (USD 14,000) since February 2013 (Chinese Car Plate Website, 2015). As a remedy to the unfairness of the auction in Shanghai, the lottery in Beijing upholds fairness as its main principle (Beijing Traffic Management Bureau, 2010). Even under the pressure of extremely low winning rates of the lotteries in 2014, a government official said Beijing would never auction license plates because it aims to protect the interests of the poor (Tengxun Newspaper, 2014). Many people posit that the poor prefer lotteries because they are more likely to benefit from lotteries than auctions (Li, 2012). Some people support lotteries because, arguably, owning an automobile is a necessity, and driving is a fundamental right (Jiang, 2013; Xue, 2004).

Further, studies mainly argue that unlike lotteries, auctions are efficient. Auction prices reveal the demand and the cost of resources, which random allocation by lotteries cannot reveal (Nie, 2013). Many studies demonstrate that allocating license plates by auctions causes less loss of total social welfare than lotteries (Hou, Peng, & Ma, 2013; Liu, 2008; Nie, 2013; Ye & Yin, 2013). The lottery had not been efficient because it is blind to mobility needs (Li, 2012). In addition, the lottery relinquished the opportunity to raise government revenue. The costs of lottery waiting time were a waste of social resources, and the low winning rates made it difficult for people with urgent mobility needs to obtain a license plate quickly (Jiang, 2013; Nie, 2013; Xuan, Ai, & Zhang, 2013). In contrast to the claim that owning an automobile is a necessity, Li (2012) argues that automobiles are luxury goods, which should be distributed based on market rules.

For the Guangzhou policy, scholars and the public believe that it incorporates both equity and efficiency concerns (Hou et al., 2013; Jiang, 2013; Zhang, 2012). Jiang (2013) argues

that the mixed mode differentiated levels of mobility needs. Some studies argue that the mixed mode is reasonable because people with urgent mobility needs can participate in the auction and the poor can enter the lottery with the hope of winning a license plate (Li, 2012).

Although the dominant view is that lotteries are fair and auctions are efficient, scholars sometimes challenge the fairness of lotteries and argue that auctions are fairer. Some studies critique lotteries as unfair stating that equal winning opportunities do not reflect mobility needs, which can only be approximated by the willingness to pay at auctions (Fan, 2013; Nie, 2013). Others critique that lotteries are unfair to new car owners and migrant residents (Jiang, 2013). Moreover, the revenue generated by auctions and invested in public transit has a positive impact on socially disadvantaged people (Chen & Zhao, 2013; Hou et al., 2013; Li, 2012). In Shanghai, the CNY 6.7 billion revenue generated in 2014 was spent on additional buses (28%), subsidies for transit transfers (23%), senior passes (14%), transit construction and maintenance (18%), Mass Rapid Transit construction (13%), and miscellaneous uses (Shanghai Financial Bureau, 2015). This revenue transfer provided redistributive benefits to the poor and non-car owners (L. Ye & Yin, 2013).

Beyond the debate on the equity and efficiency of lotteries and auctions, this regulation can be approached from many other perspectives. For instance, Singapore adopted a similar vehicle quota scheme (VQS) in 1990. Studies have discussed the factors leading to vehicle quota controls, such as the elasticity of automobile ownership and the incentives of planners (Chin & Smith, 1997; Phang, 1993). Some studies analyze the details of the auction mechanism in Singapore comparing transferable certificates of entitlements (COEs) to nontransferable ones and comparing discriminatory to nondiscriminatory auctions (Koh & Lee, 1994). Concerning the license plate regulations in China, there are many other perspectives such as analyzing the impact on traffic speed, air pollution, the number of vehicles sold annually, fuel consumption, and the relationship between auto usage and ownership (Chin & Smith, 1997; Sun, Zheng, & Wang, 2014; Yang, Liu, Qin, & Liu, 2014).

In this study, we analyze the distributional effects of the mixed mode in Guangzhou in a specific and positive manner based on individual behavioral choices. This paper per se does not answer the comprehensive normative question of whether this policy is equitable. We focus on direct outcomes, namely, those who chose lottery, auction, and non-participation alternatives, rather than indirect outcomes such as the impacts of revenue transfers. With numerous potential determinants of choices, we concentrate our analysis, albeit unexclusively, on income and automobile ownership because income is the most salient variable in any debate related to distributional effects, and automobiles are the target factor in car restriction policies.

Data Collection and Analytic Method

We worked with a professional survey company in China to collect information on Guangzhou residents. Samples were selected from a database of approximately 310,000 individuals living in Guangzhou. Emails containing the survey invitation were sent to

10,248 individuals. A total of 3,074 potential respondents visited the link. Finally, we collected 1,000 observations. Each respondent was paid CNY 20 (approximately USD 2.9) in the form of cash rewards for answering the survey.

It is worth noting that the sampling scheme here is not a simple random sampling, but a stratified random sampling. In a stratified random sampling, "the population is first subdivided into two or more mutually exclusive segments, … Simple random samples are drawn from each stratum, and these subsamples are joined to form the complete, stratified sample" (Singleton Jr, Straits, & Straits, 1993). In our research, the three strata are the non-participants, lottery, and auction participants. We adopted this sampling approach because, in each month, only a small fraction of people chose lotteries, and an even smaller fraction chose auctions. To increase the efficiency of data analysis, the two strata with small proportions of participation, namely, lottery and auction participants, were assigned higher quotas than their real proportions in the population. While there were only approximately 10,000 auction participants and 400,000 lottery participants among 12 million Guangzhou citizens each month, we assigned a quota of 200 to auction participants, 400 to lottery participants, and 400 to non-participants. More specifically, when we conducted the survey, the first question probed the past participation patterns of the respondents, and it was the filtering question to sample each stratum. This stratified sampling scheme has been proved to generate no bias in the estimation of Logit models (Ben-Akiva & Lerman, 1985). In fact, this property of generating no bias could be understood in an intuitive manner. For instance, while the whole sample is not representative, the average income difference between lottery and auction participants measures the difference in the population because they are representative within their own stratum.

The survey started with the revealed choice between lottery, auction, and non-participation alternatives from January 2015 to December 2015. Since those who won plates were not allowed to enter an auction or a lottery again, we withdrew the observations occurring after they had won. The survey included socio-demographic variables, such as age, gender, *hukou* status[1], automobile ownership, income, household size, the number of children, and travel behaviors such as primary commuting modes and travel times. We also incorporated the official data such as prices, winning rates, and numbers of entrants of lotteries and auctions. Table 1 compares the age, *hukou*, gender, and household size distributions of our sample to those of the public dataset provided by the Guangzhou government. We oversampled three-member households and 25 to 35 years old and under-sampled older individuals. However, Ben-Akiva and Lerman (1985) note that the stratified sampling scheme and the discrepancy between the sample and the population do not create inconsistency in the coefficients estimated in logit models except for the alternative-specific constant terms.

[1] Hukou is China's household registration system that identifies every person by name, birth date, gender, and the official location of residence (city and province) and type (urban or rural). Governments use hukou to indirectly control the migration of rural workers to cities by differentiating the package of social welfare granted to urban and rural workers (Afridi, Li, & Ren, 2015).

Table 1 Socio-demographics of the sample and the population

	Sample Total No.	Sample Total %	Population Total No.	Population Total %
Age Groups				
20 - 24 Years Old	114	11.4	1,862,543	18.1
25 - 35 Years Old	589	58.9	2,688,113	26.2
35 - 45 Years Old	261	26.1	2,378,475	23.1
Older than 45 Years Old	36	3.6	3,346,027	32.6
Total	1000	100	10,275,158	100
Hukou (Residence Status)				
Local Citizens	701	70.1	8,077,303	62.5
Non-local Citizens with Residence Permits	147	14.7	4,849,497[2]	37.5
Non-local Citizens without Residence Permits	141	14.1		
Other residence status (Hong Kong / Other Countries)	11	1.1	NA	NA
Total	1000	100	12,926,800	100
Gender				
Male	520	52.0	6,639,745	52.3
Female	480	48.0	6,062,203	47.7
Total	1000	100	12,701,948	100
Automobile numbers before participation				
0	391	39.1	NA[3]	NA
1	599	59.9	NA	NA
2	10	1.0	NA	NA
Total	1000	100	NA	NA
Household Income Groups (Month)				
5,000 Yuan and Less	156	15.6	NA	NA
5,000 - 10,000 Yuan	161	16.1	NA	NA
10,000 - 20,000 Yuan	519	51.9	NA	NA
20,000 - 40,000 Yuan	134	13.4	NA	NA
More than 40,000 Yuan	30	3	NA	NA
Total	1000	100	NA	NA
Household Size				
1	46	4.6	979,690	12.0
2	111	11.1	1,807,830	22.2
3	611	61.1	2,904,603	35.6
4	109	10.9	2,032,616	24.9
5	123	12.3	425,318	5.2
Total	1000	100	8,150,057	100

[2] Number of total non-local citizens includes those with and without residence permits.
[3] We cannot obtain the distribution of income, automobile numbers, and the status of license plates because there is no publically available data

We included income, automobile ownership, mobility needs, residence status, and the attributes of alternatives as explanatory variables in the models. Income is the focal point of all discussions on distributional effects. Automobile ownership is also a necessary explanatory variable since the policy targets automobiles. We used household size, number of children, one-way commuting travel time, and travel time to bus stops and rail stations to approximate mobility needs. We used the lagged terms of the alternative attributes to avoid endogeneity. The dependent variables are the revealed choices among auction, lottery, and non-participation alternatives.

We employed two choice models to analyze behaviors. The first is a multinomial logit (MNL) model with cluster-robust standard error. The cluster-robust standard error allows correlation among multiple responses across twelve months by the same individual. MNL models require an independence of irrelevant alternative (IIA) assumption (Ben-Akiva & Lerman, 1985), which, we suspect, may not hold in this context because lotteries and auctions are more closely related to each other relative to non-participation. The second model—mixed logit (MXL) model, a more flexible model form—was used to address the IIA problem. Since the dataset covers 12 choices of each individual from January to December 2015, the MXL model needs to accommodate the randomness of the error terms for each individual (Revelt & Train, 1998). Typically, there are three modeling schemes for a panel choice model regression: a fixed effects (FE) mixed logit model, a random effects (RE) mixed logit model, or a mixed logit model with cluster-robust variance estimators (Greene, 2011). This study used the mixed logit model with cluster-robust variance estimators because it imposes fewer assumptions than the RE mixed logit model and it can estimate the parameters of time-invariant variables, which an FE mixed logit model cannot do. To implement this mixed logit model with cluster-robust estimators, we used the package *mixlogit* in Stata. The specification of the utility functions is as follows:

$$
\begin{aligned}
U_{ijt} = {} & \beta_0 \\
& + \beta_1 Inc_i + \beta_2 Auto_{it} + \beta_3 Inc_i * Auto_{it} + \beta_4 Gender_i + \beta_5 Age_i + \beta_6 Edu_i \\
& + \beta_7 Child_i \\
& + \beta_8 WRLottery_{it} + \beta_9 EntrantsLot_{it} + \beta_{10} PriceAuc_{it} + \beta_{11} EntrantsAuc_{it} \\
& + \beta_{12} MigrantsWON_i + \beta_{13} MigrantsWP_i + \beta_{14} ResiYears_i \\
& + e_j + \epsilon_{ijt},
\end{aligned}
$$

where U_{ijt} is the utilities of each choice. The subscripts $i, j,$ and t denote individuals, alternatives, and time periods. Hence, $j \in \{Auction, Lottery, Non\ Participation\}$, and $t \in \{Jan, Feb, \dots, Dec\}$. The e_j term is normally distributed, and it allows the heterogeneity regarding each alternative. The ϵ_{ijt} term is the random utility following the Gumbel distribution and describing modelers' ignorance of utilities.

Results

The income distributions of the three groups overlapped significantly (Figure 3). For average household incomes, people who chose lotteries were not the most disadvantaged. They had a medium-level income, CNY 14,500 (USD 2,230) per month, which was USD 390 higher than the average income of non-participants and USD 250 lower than that of auction participants. Approximately 60% of the people who chose lotteries or auctions had at least one automobile in their households before they participated while only approximately 40% of the non-participants had at least one automobile (Figure 4). The data do not support the common notion that the poor chose the lottery and the rich chose the auction, and the data do not support the notion that the non-car owners were more likely to participate either. The participants were more socially advantaged than the non-participants.

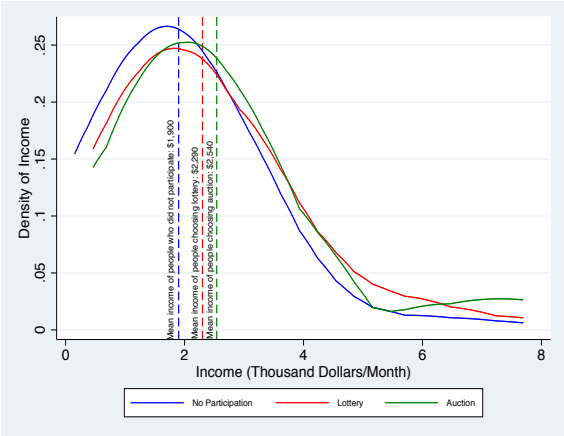

Figure 3 Comparison of income of those who chose auction, lottery, and the non-participation alternative

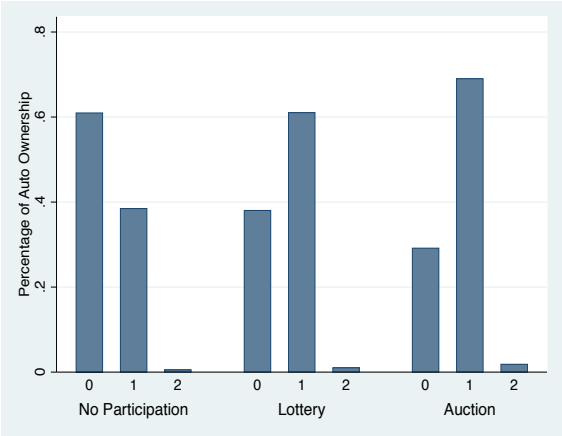

Figure 4 Comparison of auto ownership of those who chose auction, lottery, and non-participation

Table 2 shows the results of the two choice models. Both use the non-participation alternative as the base. The MXL model fit the dataset considerably better than the MNL model. The pseudo R square of the MNL model was 12.0% while the pseudo R square of the MXL model was 60.5% implying that the random alternative-specific terms are effective. The signs of the coefficients of both models are consistent, but the magnitudes are different. Our following analyses are based on the MXL model.

Table 2 Results of MNL and MXL models

		Multinomial Logit Model (MNL)		Mixed Logit Model (MXL)	
	VARIABLES	Lottery	Auction	Lottery	Auction
Socio-demographics	Income (CNY 1,000)	0.0942***	0.113***	0.299***	0.282***
		(0.0193)	(0.0239)	(0.0328)	(0.0239)
	Automobile number	2.552***	2.691***	8.287***	6.239***
		(0.296)	(0.447)	(0.617)	(0.604)
	Income * Automobile	-0.121***	-0.0925***	-0.381***	-0.129***
		(0.0199)	(0.0247)	(0.0337)	(0.0212)
	Age (Years)	-0.00621	-0.0433**	-0.131***	-0.197***
		(0.0132)	(0.0189)	(0.0220)	(0.0263)
	Gender (Male = 0)	0.0751	-0.597***	-0.00720	-2.398***
		(0.145)	(0.204)	(0.284)	(0.301)
	Education (Years)	-0.0544	-0.0553	-0.306***	-0.578***
		(0.0467)	(0.0771)	(0.107)	(0.117)
Residence Status	Migrants with Permits	0.601***	0.920***	2.972***	3.578***
		(0.208)	(0.318)	(0.476)	(0.455)
	Migrants without Permits	-0.858***	-0.0772	-5.034***	-3.367***
		(0.297)	(0.452)	(0.674)	(0.496)
	Residence Time	0.0161*	0.0443***	0.0886***	0.206***
		(0.00847)	(0.0131)	(0.0211)	(0.0234)
Mobility Needs	Number of Children	-0.492***	0.216	-0.447	0.534
		(0.177)	(0.283)	(0.351)	(0.330)
Program Attributes	Winning Rates of Lotteries	0.944***		5.219***	
		(0.161)		(0.507)	
	Participants of Lotteries	0.00795***		0.0537***	
		(0.00115)		(0.00332)	
	Price of Auctions (CNY 1,000)		0.0267***		0.107***
			(0.00363)		(0.00903)
	Participants of Auctions		0.0893***		0.550***
			(0.0139)		(0.0345)
Alternative Specific Constants	Auction dummy (mean)				-10.01***
					(1.916)
	Auction dummy (SD)				7.496***
					(0.441)
	Lottery dummy (mean)			-28.33***	
				(2.639)	
	Lottery dummy (SD)			7.764***	
				(0.378)	
	Constant	-5.488***	-4.177***		
		(1.054)	(1.343)		
	Pseudo R Square	0.120		0.605	
	Final Log Likelihood	-7697		-3453	
	Null Model Log Likelihood	-8747		-8747	
	Number of observations	9,783		9,783	

[Notes: * p<0.1, ** p<0.05, *** p<0.01]

Socio-demographic variables

Both income and automobile ownership increased lottery and auction participation, but their interaction terms had a negative coefficient. For non-car owners, income influences on lotteries and auctions were both positive and of a similar magnitude[4]. Income did not distinguish between lottery and auction participants, and lotteries by no means benefitted the poor. It is quite possible that the poor people did not participate in lotteries or auctions because the license plate was actually a permit of buying cars and the poor anticipated their incapability of affording a car. Given the mandate that license winners need to register license plates within six months and that the license is non-transferrable, i.e., it is illegal to sell the license to another person, the very poor would not even attempt the lottery. Considering that the average prices of license plate were much cheaper than cars[5], the income difference between the lottery and auction participants could be not significantly different. For car owners, high income decreased lottery participation slightly while it increased the auction participation.

Residents with more automobiles strongly preferred lotteries and auctions to non-participation. This suggests a car-dependent trajectory. People tend to buy more cars once they are already car owners. Regarding the relative impact of lotteries compared to auctions, higher automobile ownership slightly encouraged lotteries more than auctions although this difference is not robust because the automobile coefficients in the MNL model are similar. The difference is intuitive since people with more automobiles needed automobiles less urgently. Auctions allowed the affluent households with more automobiles to obtain license plates quickly while lotteries allowed the same group of people to speculate. Auctions and lotteries gave the well-off the opportunity of choice, but both are a luxury beyond the reach of the poor.

Age, gender, and education significantly influenced choices. Older people were less likely to choose lotteries and auctions, perhaps because the young needed to use automobile more often. Females were less likely to choose auctions, perhaps because men have greater social expectations when buying automobiles. Higher education discouraged participation, probably because those with a higher education realize that automobile use is associated with air pollution and carbon emission.

Mobility needs, attributes of alternatives, and others

Both *Hukou* status and residence time had a significant impact on choice. Relative to local people, migrants with residence permits were more likely to participate while migrants without residence permits were less likely to participate. This is because the government only allowed a portion of the migrants without residence permits to participate. Longer residence time led to greater participation as shown by the significantly positive coefficient of residence time.

[4] A Wald test is used to compare auction and lottery coefficients, and it fails to reject the null hypothesis that the income coefficients of auctions and lotteries are the same.

[5] As shown in Figure 2, the average auction prices of license plates were between 10,000 Yuan and 30,000 Yuan, while the price of the cheap cars was around 100,000 Yuan. The prices of license plates accounted for only about 15% of the prices of the cheap car.

Proxies of mobility needs including household size, the number of children, one-way commuting time, travel time to the nearest rail station, and the travel time to the nearest bus stop did not have a significant impact on choice. A likelihood ratio test suggests that the impact of household size, commuting time, and travel time to rail stations or bus stops on the log-likelihood was trivial. Hence, the MXL model in Table 2 only includes the number of children as the proxy of mobility needs. More children increased the likelihood of choosing auctions and decreased the likelihood of choosing lotteries although the coefficients are still insignificant. The modeling results imply that this policy could not effectively differentiate people with different levels of mobility needs casting doubt on the contention that auctions or the mixed mode could differentiate mobility needs.

Guangzhou residents responded to the attributes of lotteries and auctions. Higher prices of auctions increased auction participation, perhaps because people expected a higher price in the future, thus propelling them to choose auctions sooner. This sign is different from that of the cost of common commodities, which is often negative, because here the license plate is similar to an investment rather than consumption. For instance in a housing market, people could be more likely to invest in houses when seeing the rise of housing prices. More entrants and higher winning rates of lotteries in the previous month increased lottery participation, probably because a higher winning rate represented a larger opportunity to win and a larger number of participants created a feeling of urgency. The number of auction entrants had similar effects. People were more likely to choose auctions when the number of auction participants in the previous month was larger.

Marginal impacts of variables

Based on the MXL model, lotteries and auctions. Table 3 summarizes the marginal effects of nine variables computed at the mean values of the variables. Automobile effects had a similar magnitude as income effects. A 1% income increase led to 1.43% and 1.35% probability increases of choosing lotteries and auctions. A 1% automobile increase led to a 1.57% probability increase of choosing the lottery and a 1.18% probability increase of choosing the auction. The magnitude of age and education effects was larger than income and automobile ownership. It is interesting that income, the most discussed socio-demographic variable, did not have a dominant impact on choice. In contrast, education and age, the much less discussed variables, had a larger impact. The marginal impacts of the proxies of mobility needs and migrant status had lesser effects than socio-demographics suggesting again that the policy is not capable of differentiating people with different mobility needs.

The attributes of lotteries and auctions, such as the number of entrants and winning rates, are of a much larger magnitude than all socio-demographics and the proxies of mobility needs. A 1% increase in the number of lottery entrants increased the probability of choosing lotteries by 5.82%. A 1% increase in the winning rates of lotteries increased the probability of choosing lotteries by 2.96%. The effect of auction prices is smaller but, overall, these effects are larger than socio-demographics and the proxies of mobility needs, which were the focal point of past studies. People chose lotteries not based on

their mobility needs or even their economic condition but, rather, the opportunity to win plates and the tendency of the whole society to choose lotteries and auctions.

Table 3 Marginal effects[6] on choices of a 1% value change in variables based on the MXL Model

	Variables	Lottery		Auction	
		dy/ex (%)	P>|z|	dy/ex (%)	P>|z|
Socio-demographics	Income	1.430	0.000	1.348	0.000
	Automobile	1.568	0.000	1.180	0.000
	Age	-1.385	0.000	-2.085	0.000
	Education (Years)	-1.604	0.004	-3.026	0.000
Residence Status	Residence Time	0.444	0.000	1.035	0.000
Proxies of Mobility Needs	Number of Children	-0.116	0.203	0.139	0.105
Attributes of Alternatives	Price of Auctions	NA	NA	0.726	0.000
	Winning Rates of Lotteries	2.959	0.000	NA	NA
	Number of Participants	5.816	0.000	1.695	0.000

Limitations

Some limitations are clear. This study was fueled by the fairness debate, but we could not have an overall fairness evaluation even after we found the robust modeling results. A comprehensive fairness evaluation is a subtle and difficult topic that we cannot address given the current evidences. The marginal effects and the coefficients are computed at the mean values, so the above arguments could only hold at the average level. It implies that the rare case could happen that some poor people with strong mobility needs still participated in lotteries or auctions. Some measurement may not be very accurate. For instance, income cannot perfectly reflect the wealth of a person. While households often collectively decide to buy or replace automobiles, we did not probe the household decision-making in this study.

Discussion

This paper examined the distributional effects of lotteries and auctions on residents under the license plate regulation in Guangzhou. We analyzed the choices made between lotteries, auctions, and non-participation alternatives using individual-level data and multinomial and mixed logit models.

Income and auto ownership affected participation: both lottery and auction participants had higher incomes and more automobiles than non-participants. However, neither income nor auto ownership differentiated between lotteries and auctions. The distributions of income and auto ownership significantly overlap among those choosing lotteries and auctions. The income effects of non-car owners on lotteries and auctions were of a similar magnitude, and the income effects of car owners were trivial. Hence, there is no behavioral evidence that the poor benefited from the lotteries. Moreover, since

[6] We removed the dummy variables from this table, including gender and migrant status, because the elasticity of dummy variables does not have a valid interpretation.

the private automobile is still a luxury good beyond the reach of the poorest in Guangzhou, it is a mistake to believe that lotteries benefitted these people. The proxies of mobility needs, including household size, the number of children, total travel time, and walking time to the nearest train stations and bus stops had either no or a trivial impact on the choice between lottery, auction, or non-participation rejecting another fairness argument that the policy differentiates people by mobility needs. Neither people's socioeconomic status nor their mobility need explains their choices between lotteries and auctions.

In contrast, people responded strongly to program attributes such as auction prices, lottery winning rates, and the number of entrants. People were more likely to choose lotteries and auctions when the past winning rates, average bidding prices, and the numbers of entrants were high. The marginal effects of the program attributes were much larger than those of socioeconomic status, migration status, and mobility needs. People chose lotteries or auctions based on the odds of winning and the opportunity for speculation instead of individual economic factors or mobility needs.

Our analysis also indicates a car-dependent trajectory, that is, households that had already owned cars were much more inclined to obtain another car. Policy makers should note that car restriction policies need to focus on managing the entire trajectory of automobile growth, beyond the policy impacts in one specific time frame.

Since this study was initially fueled by the fairness discussion, we would like to link our modeling results to the fairness debates of the series of license plate regulations. As noted before, scholars and the public contended that lotteries were fair because lotteries benefitted the poor and that auctions were fair because auctions revealed the strength of mobility needs. However, our study found clear evidences that the poor did not benefit from the lotteries and the mobility needs were not important determinants of participating in lotteries or auctions. Hence according to these modeling results, the underpinnings of the two fairness contentions could not hold. However, it is worth noting that we cannot make any general normative evaluation about either of the two allocation mechanisms because a complete evaluation requires much more information of the policy results and much deeper understanding of the fairness concepts, way beyond the scope of this study.

Our investigation of this license plate regulation sheds light on lotteries and auctions as generic ways to allocate public resources. Lotteries are often seen as an allocation rule that achieves equality or benefits the poor, but they may not function this way in particular cases. In the Guangzhou case, lotteries were the tool for speculation by affluent people instead of a solution for the poor. The lottery mechanism is not a magic bullet for improving the social welfare of the socially disadvantaged groups. In the debates on the equity of allocating public resources, scholars often focus on the poorest or the richest populations; however, residents relevant to one policy may not belong to the extremes of the social spectrum, as shown in Guangzhou's case.

We note two directions for future research. First, a complete fairness evaluation needs further elaboration on how to apply a generic fairness principle to the specific license

plate regulations. This is a valuable question, which could be explored in future studies. Second, the distributional effects of this policy depend on the long-term effects such as whether and how the government uses the revenue to improve public transit. The analysis of the distributional effects could be more comprehensive if future research considers the long-term effects.

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Appendix: Mechanisms of the Guangzhou Policy

Guangzhou local government firstly announced the official document[7] regulating the license plate allocation on August 1st, 2012. It was a temporary legislation, which lasted for ten months, aiming to test the effects of the policy and the public responses before its formal implementation. A formal version, which was actually quite similar to the previous temporary one, was announced on July 1st, 2013. The two policies both specified their goals as mitigating congestion, strengthening transit-oriented travel patterns, reducing energy consumption, and improving urban environment. As a result, all the automobiles purchased in Guangzhou after July 1st, 2012 cannot register freely, but followed the requirements of the license plate regulations.

The yearly quota of the license plates was about 120,000, approximately 10,000 each month. The exact quota number was adjusted by the relevant official agencies, including the transportation bureau, the police office, and the environmental bureau. Every month, the allocation results were publically announced on around the 25rd day. Redundant license plates, if existed, would be automatically transferred to the next month, but the quota in one year cannot be transferred to the next year.

People needed to submit materials to the local transportation agencies to prove their eligibility of participating in this license plate allocation, regardless of choosing lotteries or auctions. The eligible people included the local residents with Guangzhou[8] *hukou*, the military personnel, the foreigners who have lived in Guangzhou for two years, and the residents who have no local *hukou* but have paid social insurance for two years. Besides the restrictions on the residential status, applicants also needed valid driver license and had no registered car or license plate under their names. The eligibility requirement was the same to the auction and the lottery applicants. Once allowed to participate in either lotteries or auctions, the entrants could automatically continue for three months without any further operation. The entrant was free to switch between lotteries and auctions in different months. If the entrant failed to obtain one license plate in three months, the entrant needed to extend the participation period by informing the official agency. After obtaining a license plate, the winner needed to register a car with the license plate in six months. The license plates were not tradable. In fact, these eligibility requirements are quite similar to Beijing and Shanghai, both of which use *hukou* and social insurance as the main eligibility standards.

The auction was a first-price sealed-bid type, meaning that everyone needs to pay the exact amount of money they bid and that nobody knows the prices their competitors are paying. The bidders who paid the highest amount of money obtained license plates, and among those who paid the same, the bidders who bided earlier could obtain license plates. Within one day of every month, the auction entrants completed the whole bidding process on a website set up by the local government. The deposit of participating in the auction was 2,000 Yuan, which was returned to the winners after auctions. The Guangzhou government set up a lower bound of the bidding price, which was 10,000 Yuan, but there was no upper bound. The revenues generated through the auctions were spent to develop

[7] It is called "Temporary Provision of Number Control on Small Passenger Automobiles in Guangzhou"
[8] It includes Zengcheng and Conghua, two nearby cities that officially merged with Guangzhou in 2014.

the local public transit. Compared to auctions, the rules of lotteries were relatively simple. There was no entrance fee of lotteries. All the lottery entrants had the same winning rate to get a license plate. The winning was subject to pure randomness.