An Empirical Assessment of the Impact of the Vehicle Quota System on Environment: Evidence from China

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Abstract

The rapid development of the Chinese automobile market has caused severe problems, such as air pollution and traffic congestion in recent years. A license quota has been imposed and allocated through auction by the government of Shanghai, the largest city by population in China, to control the number of vehicles in the city. This paper investigates the influence of the unique license quota system on passenger vehicle control, fleet efficiency, gas consumption, and pollutant emissions. Empirical findings suggest that the high-priced license is effective in controlling the sale of passenger vehicles. However, this high cost offsets part of the positive effect of vehicle control on the environment by effectively lowering fleet efficiency. We simulate two alternative policies based on the progressive tax systems that could control both the fleet size and the fleet efficiency more effectively; our results suggest that the current quota system is not the best choice for environmental purposes.

Keywords: Vehicle Quota System, China Automobile Market, Fleet Efficiency, Vehicle Control
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1 Introduction

Vehicle emissions have fallen in recent years in developed countries as a result of enhanced fuel efficiency (Kahn 1996). Meanwhile, air pollution due to car emissions has become a severe problem in major cities in some emerging economies in recent years. For example, vehicle emissions have become the main source of air pollution in China's large and medium-sized cities, according to the China Vehicle Emission Control Annual Report 2010 by the Ministry of Environmental Protection. This report shows that the volume of pollutants generated by motor vehicles across China in 2009 amounted to 51.4 million tons, with passenger cars contributing most of it. Furthermore, Walsh (2000) also estimated that mobile sources contributed approximately 45-60% of the nitrogen oxide (NOx) emissions and about 85% of the carbon monoxide (CO) emissions in major Chinese cities. To control the vehicle population and thereby mitigate these environmental problems, the Chinese central government has applied tax policies, such as fuel and consumption taxes, which have proven to be effective in controlling emissions (Xiao and Ju, 2013). Some local governments have implemented more stringent policies. For example, Beijing applied the "odd-even license plate rule,"[1] while Shanghai, the largest city by population in China, imposed a vehicle quota system (VQS) and allocated the quota through a license auction. Such policies are unique, and other emerging economies could use them as models to address their problems.

The effectiveness of the VQS seems evident, but it has never actually been identified. Previous studies on the similar VQS of Singapore suggest that it is effective in vehicle control. However, they cannot disentangle the effect of the VQS from other factors such as the worsening economic situation (Seik 1998) or the lessened utility from cars, which may stem from improvements to public transportation or worsening traffic congestion. So, the effect of the VQS on vehicle control may not be that obvious. Nevertheless, it is imperative to identify its impact on energy consumption and air pollution since more cities in China are following Shanghai's example to apply quotas even though they do not have quantitative evaluation on the effectiveness of this policy.[2]

This paper investigates the impact of the VQS of Shanghai on vehicle control, fleet efficiency, gas consumption, and pollutant emissions. First, we compare the sales of passenger vehicles and fleet efficiency

[1] The regulation was introduced on July 20, 2008, to ease congestion and reduce pollution during the Olympics and Paralympics. It limited the city's 3.3 million private cars to alternate days on the road, according to whether they had even- or odd-numbered license plates.

[2] Beijing imposed the vehicle quota in January 2011, followed by Guiyang in August 2011 and Guangzhou in August 2012.

using registration data for Shanghai and Beijing, two cities with similar average income levels and household numbers. Our empirical findings show that car sales in Shanghai are much lower but skewed toward less efficient cars, resulting in a lower fleet efficiency. But this difference could also be attributed to some confounding factors, such as the market structure or demand conditions. Second, to identify the effects of the VQS, we apply Berry, Levinsohn, and Pakes (1995, hereafter BLP) methodology to the car registration data for these two cities and estimate consumer preference over some key car features and prices. Using the model estimates, we assess the effect of the VQS by simulation, controlling for other factors that might influence the evaluation. The comparative statics between scenarios suggest that the license fee in Shanghai could decrease new car sales by 48.40% and gas consumption by 47.67%, reducing the emissions of three criteria pollutants to almost half their actual volume. This implies the license quota is effective in controlling the fleet size and reducing gas consumption and pollutant emission. However, the lower value of local intrinsic preference to cars in Shanghai also plays an important role in vehicle control. The fleet distribution is skewed toward less efficient cars because consumers who can afford the license fee are less price sensitive, so they will choose high-end products that are usually less efficient.

The VQS mechanism that supports vehicle control is selling a quota of licenses through an auction, which increases the cost of owning a vehicle. License quotas acquired through auction are very expensive and prices increase over time (see Figure 1). By increasing the cost of car ownership, the VQS can effectively control the vehicle population. However, the overall influence of the VQS on fleet efficiency is ambiguous and controversial. On the one hand, as the license quota becomes more expensive, low-income (or price sensitive) customers drop out by self-selection. High-income customers intend to purchase high-end vehicles with larger cylinders; this shifts consumer demand in favor of more luxury cars but at the expense of efficiency (Koh 2003). On the other hand, licenses are perfect complements to vehicles. Budget constraints may cause consumers to choose a fuel efficient vehicle to compensate for the cost of the license. This is the income effect of the quota auction. Although the overall effect on fleet efficiency is ambiguous, it is very important to quantify this effect since it "has important implications for policies that aim to address climate change, local air pollution, and a host of other externalities related to gasoline consumption" (Li, Timmins and von Haefen, 2009).

Previous research on emission reduction has focused on tax policies (Xiao and Ju 2013, Dahl, 1979, Parry and Small, 2005, Fullerton and Gan, 2005, Feng, Fullerton, and Gan, 2005, and Bento et al., 2009) and other compulsory nontax regulations such as CAFE (Crandall, 1992, Sterner, Dahl and Franzen, 1992, Koopman, 1995, Agras, 1999, and West, 2004). To our knowledge, little research has studied the impact of license quotas on vehicle control, except for Xiao, Zhou and Hu (2013), who investigate the influence of the VQS on the market structure. Even less evidence exists evaluating the environmental effect of license quotas. Unlike taxes, which are proportional to the car price (such as sales or consumption taxes, Xiao and Ju, 2013) or vehicle miles traveled (such as fuel or emission taxes, Barnett 1980, De Borger 2001, Fullerton and West 2010, Innes 1996, Plaut 1998, and West 2004), the license fee is a lump-sum payment independent of car values or other car features, such as cylinder capacity. So, it eventually works as a regressive tax, which does not favor more efficient cars and therefore may lower the overall fleet efficiency, offsetting the positive effect of vehicle control on the environment. This implies that policies controlling both fleet size and efficiency would be better substitutes for the VQS. We derive an optimal tax scheme progressive in fuel consumption, maximizing the fleet efficiency at any fleet size. Using counterfactual analysis to contrast the effectiveness of such optimal tax and a real progressive tax, the first registration tax in Hong Kong, to that of the VQS, we find that both taxes are as good as the VQS in fleet size control but lead to higher fleet efficiency.

Extant research on vehicle quota studies the VQS in Singapore (Koh 2003, Koh and Lee 1994), which is different from the one in our study . First, the Singapore quota is valid for 10 years while the Shanghai quota is lifetime, so the Shanghai lump-sum quota price can be regarded as part of the vehicle cost. Second, there are five categories by car type and cylinder size in Singapore's VQS (Chu, Koh, and Tse 2004), and each category has a separate quota. This means lower-income motor vehicle buyers would not have to bid against wealthier buyers for quota licenses (Tan 2003). By contrast, the Shanghai quota system does not distinguish between types of cars. Thus, low-income consumers are crowded out as the quota price increases, which shifts the income distribution of vehicle consumers toward the high-income group. Gertler, Locay, and Sanderson (1987) show that high-income consumers may prefer high quality/high price to low quality/low price options, while low-income consumers are opposite; therefore, such a change in income distribution will change the demand structure and so affect fleet efficiency since high-end cars usually feature luxury but sacrifice fuel efficiency.

This paper contributes to the literature in the following ways. First, we use stylized facts to show the effect of the VQS on the distribution of vehicle fuel efficiency. Our empirical findings show that the distribution of fuel efficiency for Shanghai lies above any other Chinese provinces, meaning that the share of fuel efficient vehicles is lower in Shanghai than in other provinces. Second, this paper further analyzes the factors contributing to the difference in distribution of fuel efficiency. Our empirical results suggest that the self-selection effect of the VQS crowds out low-income consumers and shifts the demand toward higher priced but less efficient vehicles because of high-income consumers' preference. Third, this paper disentangles the role of the VQS in controlling the number of vehicles from other confounding factors, such as alternatives to purchasing a private vehicle. We find that the VQS is an effective instrument in quantitative restraint; however, the lower value of local intrinsic preference for cars in Shanghai also plays a significant role. One political implication of this finding is that improving public transportation options can curb the dramatic growth of vehicle population. Finally, we propose and estimate an optimal tax scheme, and compare the present VQS to the optimal tax scheme and a realistic alternative policy, the first registration tax in Hong Kong. We conclude that the tax system can serve the purpose of vehicle control as effectively as the VQS , without increasing government spending. Moreover, the tax policies can enhance fleet efficiency and further reduce pollutant emissions and gas consumptions. This suggests that the government has better choices than the VQS to protect the environment.

The rest of the paper is organized as follows. Section 2 briefly reviews the history of the license auction system and shows the stylized facts about the effect of the quota system on vehicle control and fuel efficiency distribution. Section 3 describes the empirical model and estimation method. Section 4 discusses the details of the estimation issues. Section 5 introduces the data. Section 6 shows our empirical findings. Section 7 examines the effect of the VQS by counterfactual analysis. Finally, Section 8 concludes the paper.

2 License quotas

2.1 Brief history of the license quota

Shanghai issued its first private car license plate in 1986, eight years after the start of Chinese economic reform. Since then, the city has been trying to control the number of private cars on its street due to the limited capacity of its road system. In 1994, the local government set a quota on how many new licenses it would issue each year, selling them in sealed bids reserve price auctions.[3] From 1994 to 1999, only 11,000 licenses were sold in this way. In 2000, Shanghai Municipal People's Congress issued the Regulations of Motor Vehicles in Shanghai, and the open auction without reserve price became the new method to acquire a license. As the demand for private cars soared, the price of the license plates increased dramatically (see Figure 1).

The Regulations were replaced by the Law of the People's Republic of China on Road Traffic Safety on May 1, 2004. In the same month, the Assistant Minister of Commerce announced that the license auction in Shanghai violated the law, and the rumor spread that the quota system was illegal and would be canceled. The minimum price of licenses dropped dramatically to 10,800 in that month, compared to RMB 44,200 in April.[4] Since then, the debate whether the license auction should be canceled has continued, while the license prices have skyrocketed. Overwhelming criticism over the rapidly growing prices forced the government to adjust the auction rule in January 2008, which dropped the price temporarily. Since then, the steady price increase indicates that the demand for the license quota has shifted up for some reason.

2.2 Second-hand market and other options

Because licenses in Shanghai do not expire, the market for second-hand licenses is also very active. Monthly transaction volume is about half that of the newly released quota licenses. Usually, the transaction price is a few hundred to thousand renminbi higher than the average auction price for new licenses.[5] This is actually the market clearing price, since consumers who lose in the auction can buy a license in the second-hand market as long as their willingness to pay is higher than the transaction price. So eventually, the VQS realizes the quantitative control by increasing the cost of vehicle ownership. Hence, we will apply a model considering the consumers' budget constraint rather than the quantitative constraint in the

[3]The first auction for the plates was held at the Shanghai Center July 18, 1992. The winning bid for the first plate was RMB 305,000 *yuan* (or USD$ 55,860). At this auction, 14 plates were sold. Different from the current auction for quota, the bidding items were specific license numbers.

[4]Figure 1 shows the average transaction price.

[5]In recent years, scalpers have controlled the second-hand market for license quotas, pushing the price gap between second-hand market and the auction market to enlarge from a few hundred in 2010 to over RMB 5,000 yuan in January 2013. There originally was no effective policy preventing scalpers from getting involved in the city's monthly auction. A new policy was introduced in July 2012 to rein in price speculation. The rule, which extends the period motorists must keep a license plate from one year to three years, is supposed to deter scalpers from reselling licenses. But the average price of a Shanghai license plate has increased more than 28% since the policy was introduced due to the overwhelming demand.

following analysis.

Instead of paying for an expensive Shanghai plate, drivers in the city often register their cars in a neighboring province. However, some local traffic regulations make this option less attractive. During rush hours,[6] for example, vehicles without local license plates cannot drive on the flyovers in the city,[7] which significantly increases the driving time due to the severe traffic congestion elsewhere. Also, vehicles must be inspected annually where the vehicle is registered, which inconveniences drivers licensed in other cities . Therefore, licensing a vehicle in another province is not an effective substitute for a Shanghai license.

2.3 Stylized facts about the effect of the VQS

The VQS has two contradictory effects. On the one hand, it has effectively controlled the number of private cars. Using Beijing, a city with a similar economic situation, as an example for comparison, we show in Table 1 that the number of private passenger vehicles in Shanghai is only $1/3$ of that in Beijing by the end of 2009, compared to $3/5$ in 1994. On the other hand, the cars on the road in Shanghai have become bigger and less fuel-efficient. Figure 2 displays the cumulative distribution of fuel efficiency for newly registered cars in January 2009 by province.[8] Apparently, the share of cars with a fuel efficiency higher than any given value is less in Shanghai than in other provinces.[9] In particular, the fleet efficiency in Shanghai is about 8.5% lower than that in Beijing. These stylized facts suggest that the VQS can control the fleet size, but at the cost of fleet efficiency.

However, the difference in vehicle sales and efficiency distribution could be attributed to other factors such as demographic characteristics, market competition structure, and consumer preference. Without controlling for these factors, we cannot identify the impact of the quota system on car sales and fleet efficiency. Considering these factors, we first estimate the demand parameters by applying the revealed preference method similar to the BLP (1995) framework to the sales data of two Chinese cities, Beijing

[6]The rush hours are 07:30-09:30 and 16:30-18:30 from Monday to Friday.

[7]A fine of 200 yuan applies for violations.

[8]We first sort the cars by fuel efficiency and then calculate the cumulative sales for each efficiency level. The cumulative distribution by province is then defined as the ratio of cumulative sales over the total sales by province. As shown in Figure 2, the distribution for Shanghai lies above that for any other provinces. Borrowing the definition of stochastic dominance, we say the distribution for Shanghai is first-order stochastically dominated by that for any other provinces.

[9]Using data for the other months in 2009 and 2010, we get the same results.

and Shanghai. Next, we assess the impact of the quota system on the fleet size, fleet efficiency, gas consumption, and exhaust emissions through simulation using the estimated demand model.

3 Model

Assume that consumers are heterogeneous in household income and idiosyncratic tastes. Then the indirect utility of consumer i purchasing product j from segment g in market m at time t, taking into account the budget constraint, is given as follows,

$$u_{ijmt} = \alpha \ln(y_{imt} - p_{jmt}) + \delta_{jmt} + \zeta_{igmt} + (1-\sigma)\varepsilon_{ijmt}, \tag{1}$$

where α is the price coefficient; p_{jmt} is the cost for product j in market m. Given the fact that the license quota and cars are perfect complementary goods, the product cost for a Shanghai consumer is the summation of car price and license fee. δ_{jmt} is the mean utility of consuming the physical characteristics of product j in market m at time t. This is different from the traditional definition of mean utility in BLP (1995) in that it is the use-value of a product, measuring consumers' preference over some product characteristics other than price. We further parameterize the mean utility to be $\delta_{jmt} = X_{jmt}\beta + \xi_{jmt}$, where β measures consumers' preference over some key product features captured by the vector X_{jmt}. The quality index, ξ_{jmt}, captures all the other features, which are observable to the consumers but unobservable in our data. We assume this variable follows a mean zero distribution. ζ_{igmt} is a nested logit random taste that is constant for products in the same segment. σ is the nested logit parameter, $\sigma \in (0,1)$, measuring the correlation of consumers' preference over the within-segment products: the correlation goes to one as σ approaches one; and ε_{ijmt} is the consumer-specific deviation from the mean utility.

Consumers will choose a product to maximize their utility. They may also choose to buy products out of the data set or not to buy as well. We define such a case as an outside option, and standardize the price and mean utility of this option to be zero for all individuals, so the utility of the outside option is given by,

$$u_{i0mt} = \alpha \ln(y_{imt}) + \zeta_{i0mt} + (1-\sigma)\varepsilon_{i0mt}.$$

The utility function (1) is composed of two parts: the utility from consumption of product quality and the utility from consumption of other complex goods using the residual savings. There are two features of this indirect utility function: first, the marginal rate of substitution of complex goods for vehicle quality, $MRS_{jy} = \frac{\frac{\partial u}{\partial (y-p)}}{\frac{\partial u}{\partial q}} = \frac{\delta}{\alpha}\frac{1}{(y-p)}$, increases as the vehicle price increases, meaning that consumers must give up more complex goods for high end cars. Second, the MRS_{jy} decreases when consumers' savings increase. Hence, consumers with higher savings are more likely to choose high quality/high price vehicles, while the low-saving consumers will choose the low quality/low price vehicles.

Based on BLP (1995), the above specifications imply that the product demand in terms of market share can be described by a random coefficient nested logit model as follows:

$$S_{jmt} = \int s_{ijmt}(y_{imt})dy_{imt} = \int \frac{e^{\frac{\alpha \ln(y_{imt} - p_{jmt}) + \delta_{jmt}}{1-\sigma}} \cdot 1(y_{imt} \geq p_{jmt})}{D_{igmt}^{\sigma} \sum D_{igmt}^{1-\sigma}} dy_{imt}, \tag{2}$$

where $D_{igmt} = \sum_{k \in g}[e^{\frac{\alpha \ln(y_{imt} - p_{kmt}) + \delta_{kmt}}{1-\sigma}} \cdot 1(y_{imt} \geq p_{kmt})]$ is the inclusive value of all the products within segment g in the feasible set of consumer i in the market m at time t. As shown by equation (2), the aggregate market share is the integration of individual market shares over income distribution. In the model, we denote $\theta = (\alpha, \sigma, \beta)$ as the set of demand parameters to be estimated.

4 Estimation

4.1 Identification method

By matching the predicted market shares to the observed ones in equation (2), we can estimate the model parameters. Since integration is not feasible, the integral is approximated by the following equation,

$$S_{jmt} = \frac{1}{ns}\sum_{y_{imt}} s_{ijmt}(y_{imt}) = \frac{1}{ns}\sum_{y_{imt}} \frac{e^{\frac{\alpha \ln(y_{imt} - p_{jmt}) + \delta_{jmt}}{1-\sigma}} \cdot 1(y_{imt} \geq p_{jmt})}{D_{igmt}^{\sigma} \sum D_{igmt}^{1-\sigma}}, \tag{3}$$

where, y_{imt} is random draw from lognormal distributions with estimated parameters obtained by the approach described in the Appendix. We set the number of random draws ns to be 2,000.

Following Nevo (2000) and BLP (1995), we use a three-step method to estimate the model parameters. First, for each value of the random coefficient (α) and nested logit parameter (σ), we estimate the mean utility δ_{jmt} using the contraction mapping method. We update δ_{jmt} to match the predicted market shares to the observed ones by iteration, until the changes of δ_{jmt} meet the following tolerance criteria: the maximum difference between two consecutive sets of δ is less than 10^{-9}, and the average difference is less than 10^{-10}. Second, we estimate the parameters in the mean utility with the generalized method of moments. Formally, the moment conditions are given by,

$$E[\delta_j(\alpha,\sigma) - x^d\beta | z^d] = 0,$$

where z^d is a vector of variables which are mean independent of unobserved product characteristics, ξ. Given the fact that the price is correlated with unobservable characteristics and so endogenous, we need instrumental variables for the moments. We discuss this in the next section. Finally, we search for the optimal value of (α and δ) to minimize the following objective function,

$$m'(\theta)Wm(\theta), \tag{4}$$

where, $m(\theta)$ is the moment condition and W is a weighting matrix.

4.2 Instruments

The prices is endogenous since it is determined by the unobservable product characteristics, which calls for instrumental variables (IVs) for the moment conditions. We apply two sets of IVs to our estimation.

The first set of IVs consists of variables measuring the exogenous product attributes. The instruments along this line include the products' own observed characteristics, such as width, length, fuel efficiency, and horsepower; the sum of the above characteristics of the other products within the same segment and produced by the same firm; and the sum of the above characteristics of products within the same segment but produced by the other firms. BLP (1995) suggest that these are optimal instruments since they enter the pricing equation derived from the first-order condition of the profit maximization problem.

The second set of IVs is the number of markets, defined at the city level, in which a car model has presence. Entry to multiple markets may lower the city-level costs, such as advertisement expenditures. Hence, the number of markets is correlated with price and independent of the unobservable product characteristics, making it a valid instrument.

5 Data description

Our data record the provincial monthly vehicle registration information of each car model produced domestically between January 2009 and December 2010.[10] During the sample periods, Shanghai is the unique city that has a license quota, which is allocated through auction. The difference in sales and its distribution over the fuel efficiency of the new vehicles between Shanghai and the other provinces, therefore, allows us to investigate the influence of the quota price on vehicle control, fleet efficiency and the environmental issues. This is a unique feature of this data set. Previous research about the VQS of Singapore lacks counterparts as a control group in the economy, so its impact is unidentifiable. We choose Beijing as contrast for Shanghai since these two metropolitan areas are similar to each other in many ways. Beijing is the political center of China and the economic center of North China, while Shanghai is the economic center of East China. As shown by Table 1, the two cities are very similar in average income, number of households, and average number of people in a household. The main difference between them is that area of Beijing is about 2.6 times that of Shanghai.

We drop the observations registered for business use since business consumers are quite different from private consumers. We also drop observations for Shanghai in December 2010, since the price of licenses is abnormally low in that month due to some technical errors. Observations with monthly sales of less than five are also dropped in both markets. Since the quota system only applies to consumers in the urban districts and not to those in the suburban districts, and the household incomes are quite different between urban and suburban areas, we use registration information for the urban districts.[11] The number of new registrations is different from the monthly quota in Shanghai because it incudes the number of license

[10]Data are obtained through private arrangement. To protect the proprietary information of the data provider, we do not release the data source. The imported cars accounted for 8.4% or 9.9% of all new registrations during the first ten months of 2010 in Beijing or Shanghai, respectively. Most of the vehicles are luxury cars. Following the literature, we did not use the registration information for imported vehicles in our analysis.

[11]For Shanghai, the urban districts include the following: Baoshan, Changling, Hongkou, Huangpu, Jing'an, Luwan, Putuo, Pudong, Xuhui, Yangpu, Zabei, and Minhang; for Beijing, urban districts include Chanping, Caoyang, Congwen, Daxing, Dongcheng, Fangsan, Fengtai, Haidian, Shijingsan, Shunyi, Tongzhou, Xicheng, and Xuanwu.

acquired in the second-hand market. This justifies our argument that the license price clears the market every month and thereby we can assess the effect of the VQS on demand by estimating the impact of the license price.

The data set provides us with the registration location of a new car (e.g., Pudong district in Shanghai), registration time (e.g., June 2010), vehicle nameplate, brand, firm, country of origin, and purpose of usage (private or business). We further collected car features from the monthly magazine Autocar and the website auto.sohu.com. The prices are manufacturer suggested retail prices (MSRP) of the base model among all the models with the same nameplate available in the market. Physical characteristics include dimensions (width and length), engine characteristics (horsepower), and performance (fuel efficiency). We also obtain the average monthly license price of the vehicle quota auction in Shanghai published online.

We generate some dummy variables to measure the following fixed effects: local brand effect, time effect, brand effect, and market effect. The local brand effect is measured by two dummy variables, equal to 1 if product j is produced and sold in Shanghai or Beijing, respectively. The coefficients of these two terms reflect consumers' preference for the local product. We use year dummy (baseline is 2004), month dummy (baseline is January) and market dummy (= 1 if $m = Beijing$) to measure the time and market effects. The market is defined at the city level. The coefficient for the city dummy measures consumers' intrinsic preference for vehicles in Beijing relative to that of consumers in Shanghai. A four-dimension dummy vector is used to indicate the products' origin of brand. Each dimension of the vector is a binary variable, equal to 1 if the origin-of-brand falls in the corresponding country/area, including America, Europe, China and Japan. The baseline of the origin-of-brand dummy vector is Korea, corresponding to zero.

There were 484 different car models sold in 2009 and 2010 as shown in Table 2. These car models can be categorized into five segments: mini with 37 models; small, 149; intermediate, 206; large, 26; and luxury, 66.[12] The geographic market is defined as the whole metropolis. The number of observations at model-market-month level is $10,534$. Table 3 shows the correlation between the continuous variables in the sample. Intuitively, price is positively correlated with the key vehicle features, such as horsepower, fuel efficiency, width, and length. Sales are negatively correlated with price.

[12] See the Appendix for segment definitions.

6 Estimation results

The parameter estimates are presented in Table 4. Model (i) is a standard logit model without control of within-segment correlation between alternative choice options. Model (ii)- (iv) are nested logit models: model (ii) does not take into account the endogeneity problem, while model (iii) does. Model (iv) is the full model taking into account both the endogeneity problem and budget constraint.

The main difference between models (i) and (ii) lies in the price coefficient: the coefficient in the nested logit model is more than three times that in the logit model, meaning that consumers are actually more price sensitive taking into account the within-segment correlation. When consumers' preference over options in the same segment is correlated, a drop in the price of any car will attract more demand from the other cars, leading to a higher price elasticity. The price coefficient in model (iii) becomes almost triple in absolute value after controlling the endogeneity problem because the unobservable characteristics are positively correlated with the price, which will underestimate the impact of price on consumers without controlling the endogeneity. The estimates of within-segment correlation for models (ii)- (iii) are similar, about 0.6. This indicates that consumers' preference over car models within the same segment is highly correlated.

Our full model takes into account consumer heterogeneity in incomes. This model is superior to the other models in that it controls both the endogeneity problem and budget constraint. Thus, we will use empirical results from this model for our discussion and counterfactual analysis.

The price coefficient is positive and significant, meaning that the income effect is positive to the consumer utility. Table 5 summarizes the corresponding price elasticity computed using the estimated price coefficient given by,

$$\frac{\partial s_j}{\partial p_k}\frac{p_k}{s_j} = \begin{cases} -\alpha \frac{p_k}{s_j}\frac{1}{ns}\sum_{y_i}\frac{1(y_i \geq p_j)}{y_i - p_j} s_{ij}\frac{1-\sigma\bar{s}_{ij/g}-(1-\sigma)s_{ij}}{1-\sigma} & \text{if } j = k, \\ \alpha \frac{p_k}{s_j}\frac{1}{ns}\sum_{y_i}\frac{1(y_i \geq p_j)}{y_i - p_j} s_{ij}\frac{\sigma\bar{s}_{ik/g}+(1-\sigma)s_{ik}}{1-\sigma} & \text{if } j \neq k,\ j,k \in g, \\ \alpha \frac{p_k}{s_j}\frac{1}{ns}\sum_{y_i}\frac{1(y_i \geq p_j)}{y_i - p_j} s_{ij}s_{ik} & \text{otherwise.} \end{cases} \tag{5}$$

Table 5 shows that the average monthly model level elasticity is -5.36 and the range of variation is not big. Consumers are heterogeneous in their incomes, and so are their price elasticities. All else equal, high-income customers are less price sensitive, which can be observed in equation (5). The cross elasticity is much smaller in magnitude, which is reasonable given that the time period is only a month and the number of competitors is large.

The parameters of car characteristics are of the expected sign. Consumers prefer large (wide and long), powerful, but fuel efficient cars. These results, together with the estimate of within-segment correlation, coincide with Deng and Ma (2010).

Consumers prefer products made by the firms in their cities: the probability a consumer will purchase a locally produced vehicle is 43.48% or 16.08% ($exp(0.361)-1$ or $exp(0.149)-1$) higher than the probability of purchasing a nonlocal vehicle in Beijing or Shanghai, respectively. Previous research also found similar results (Grigolon and Verboven 2013). Two possible reasons could explain such findings: first, it is easier to get spare parts or repairs from the local firms; second, local residents may have intrinsic preference for the local firms.

The coefficients of origin-of-brand dummies show that consumers prefer European (such as Volkswagen and Audi) and Japanese (such as Honda and Toyota) cars to Korean ones (such as Hyundai); consumers are indifferent between American cars (such as Ford and GM) and Korean cars. Indigenous brands are the least preferred.

The dummy for Beijing is significantly positive (0.623), implying that the purchase probability in Beijing is 1.86 times that in Shanghai. In other words, the intrinsic preference for purchasing vehicles is higher in Beijing. One possible reason is that the public transportation in Shanghai is more convenient. The length of metro lines in Shanghai was 35% more than in Beijing as of 2010 (Table 1). Given the fact that the area of Shanghai is less than half that of Beijing, this means the metro network is much denser in Shanghai.[13] A second possible reason is that, since the area size of Shanghai is less than half of Beijing, the average commuting distance could be lower in Shanghai, and so driving is less necessary. Third, as shown in Table 6, there are 93 more car models available in Beijing, and their average price is RMB 20,000 lower than the average of the sample mean. These low end cars enlarge the choice set of the marginal consumers who probably would give up purchase otherwise. By contrast, Shanghai only has two unique car models, with much higher prices than the average.

[13]Reports suggest that a significant portion of the revenue from the license auction has been spent on the construction of public transportation, like subways, in Shanghai.

7 Counterfactual analyses

In this section, we use the estimated demand model to assess the effect of the VQS, and compare its effectiveness between Beijing and Shanghai, which have different demand conditions. In this way, we are able to endentify the impacts of the VQS and various other factors . Using the data from the income distribution and vehicle choice set available in June 2010 in Shanghai and Beijing, we estimate the car sales, fleet efficiency, gasoline consumption, and emission volumes of three criteria pollutants in two counterfactual scenarios: (i) we remove the license fee in Shanghai, and (ii) we assume consumers in Beijing have to pay the license fee. There are three sub-scenarios for the second case: (ii) the license price is set to be the same as in Shanghai; (ii') final sales is set to be the same as that in Shanghai and the corresponding license price is estimated; and (ii") the final sales is set to be the same as the real monthly quota of Beijing. The null scenario is defined as the condition observed in June 2010 in Shanghai or Beijing. The comparative statics between the null and simulated scenario for each city show the impact of the VQS, while a cross comparison between Beijing and Shanghai shows the impact of the market structure and demand conditions on the above listed measurements.

We conduct the counterfactual experiments as follows. First, we calculate the mean utility using the estimated parameters. At this stage, the total payment and the intrinsic preference for vehicles vary over scenarios. Since the total sales of Beijing and Shanghai constitute a small portion of China's national sales (10.36% in 2010), we assume the VQS does not change car prices nationwide. Second, sampling with replacement, we make a half-million random draws of the income y_{imt} and idiosyncratic error term $\zeta_{igmt} + (1-\sigma)\varepsilon_{ijmt}$ from the income distribution and extreme value distribution, respectively. Each random draw simulates a household's income and idiosyncratic taste. These two steps generate the utility of various households i purchasing vehicle j at market m and time t, u_{ijmt}. Third, consumer i is assumed to choose the product with maximum utility, subject to her budget constraint. The addition of a license fee may reduce the choice set of cars that a consumer can afford. In this way, we can find her optimal choice, j^*, its price p_{j^*mt}, and the probability for her optimal choice. By aggregating the choice probability for the same product over individuals, we derive the market share for each product and the total sales. The fleet efficiency is the average efficiency weighted by the market shares. Finally, we sort the products by fuel efficiency, calculate the cumulative density function (CDF) in fuel efficiency, and plot the CDF for various scenarios.

7.1 Vehicle control and fleet efficiency

Table 7 shows the comparative statics for counterfactual analyses. Comparing the sales between the null and simulated scenarios, we find that a license fee of RMB 40,380 will decrease sales by 48.4% or 47.68% for Shanghai or Beijing, respectively, indicating that the quota system is effective in vehicle control.

The impact of the VQS on fleet efficiency is illustrated by Figure 3. Based on the consumers' decision whether or not to purchase a vehicle in the null scenario, we categorize Shanghai consumers into two groups: buyers and nonbuyers. In Figure 3, we depict the distribution in fuel efficiency of buyers in the null scenario in Shanghai as cdf1, and the efficiency distribution of buyers and nonbuyers in the counterfactual scenario (i) as cdf2 and cdf3, respectively. It shows that cdf2 shifts to the left of cdf1 after removing the license, and cdf3 lies to the right of cdf1. That is to say, the buyers would buy less efficient cars (on average 1.163% less efficient) when they do not need to pay the license fee and so their budgets can afford higher priced but less efficient vehicles; and the nonbuyers would buy more fuel efficient cars (on average 3.663% more efficient) since their budgets are lower. The gap in the distribution between cdf2 and cdf3 suggests that high-income consumers are more likely (or more able) to purchase less efficient cars since the only difference between buyers and nonbuyers is their income. In conclusion, on one side, license fees screen out low-income consumers, who otherwise would have purchased fuel-efficient vehicles, and so lower fleet efficiency; on the other side, however, license fees also lower the budget of the high-income consumers and force them to choose fuel-efficient cars. Overall, the selection effect dominates the income effect, and the fleet efficiency is lower. As shown in Table 7, although the fleet efficiency dropped only 1.23% due to the license fee, such a change leads to a large-scale increase of fuel consumption since the mileage and car population are large numbers over time. Also, the lower fleet efficiency puts the VQS under criticism since the system conflicts with central government policies like the corporate average fuel consumption (CAFC).

Five ministries or departments of the central government officially released the Passenger Vehicle Corporate Average Fuel Consumption Calculation in March 2013,[14] but this policy actually has been in effect since 2012. The CAFC applies to all passenger vehicles sold within China, including new energy vehicles such as battery electric, plug-in hybrid, and fuel cell vehicles. It represents the central government's

[14]The five ministries or departments include the Ministry of Industry and Information Technology, the National Development and Reform Commission, the Ministry of Commerce, the General Administration of Customs of the People's Republic of China, and the General Administration of Quality Supervision, Inspection, and Quarantine of the People's Republic of China.

resolution to control fleet efficiency. The VQS of Shanghai, however, conflicts with this policy. One of the policy provisions specifies that the average corporate fuel consumption must be no more than 6.9 liters/100km by 2015 (or equivalently, no less than 14.49km/liter). For each year before that, each firm has a progressive target, which is a sales-weighted average of target fuel consumption for individual car models.[15] Table 8 displays the estimated and the target corporate average fuel consumption in 2012 for the top 10 manufacturers with or without the license fee, assuming the license fee will not change the technical surface of the products but will change the sales weights. Apparently, the license fee increases the corporate average fuel consumption for the major manufacturers, making it more difficult for the CAFC policy target to be realized.

If an alternative policy can shift the demand from the high-income consumers to the low-income consumers, the fleet efficiency would be higher without sacrificing vehicle control. One option is to allocate the quota randomly, which is in fact the practice of the Beijing government. From 2011, Beijing also imposed a quota on vehicle licenses. Different from the quota policy in Shanghai, the Beijing quota is allocated through a lottery policy. Consumers can obtain a license randomly at negligible costs but with substantial luck. This allocation procedure is the same as our simulated scenario (i) since the simulated incomes are randomly drawn and the individuals do not need to pay the license fees. The quota determines the final sales but will not influence the market share of each product. Hence, the simulation results show that given any quota, fleet efficiency will be higher under the lottery policy than under the sales policy. However, a significant concern about this option is that it will result in welfare loss, compared with auctions, since the consumers with higher willingness to pay may not be able to acquire a license. Another option is to use a progressive tax. We will discuss this option in more details in the next section.

The difference in sales and fleet efficiency between the null scenario of Shanghai and scenario (ii) stems from the differences between Shanghai and Beijing in demand shifters other than the license fee, such as intrinsic preference, the preference for local vehicles, and income distribution. Compared with the null scenario of Shanghai, sales under the license fee in Beijing are more than double that in Shanghai, due to the much higher intrinsic preference for vehicle purchase in Beijing ($\beta_{BJ} = 0.6225$). To control vehicle sales to the same level as in Shanghai, the results for scenario (ii') show that the license fee, RMB 85,507, must be more than double the license fee in Shanghai. Even if the quota is increased to 20,000, which is the

[15] The target fuel consumption depends on vehicle weight and type of transmission. Since the vehicles with manual transmissions are more fuel efficient, the target fuel consumption for manual-transmission vehicles is usually lower. We list the ratio of vehicles with manual transmissions for the top 10 manufacturers in Table 8.

real monthly quota for Beijing, estimation results for scenario (ii") show that the license fee will be higher than that of Shanghai. This suggests that the lower preference for vehicle purchase in Shanghai plays an important role in vehicle control. Furthermore, the effective way to reduce traffic congestion in Beijing is to invest more on public transportation and improve the values of alternative options to purchasing a private vehicle, rather than simply mimic Shanghai by imposing a quantitative constraint.

7.2 Gas consumption and pollutant emissions

The above analyses show the controversial effects of the VQS: on the one hand, it can control vehicle sales, leading to lower emissions; on the other hand, it lowers fuel efficiency, resulting in higher emissions. To accommodate these two effects and assess the overall effect of the VQS intuitively, we estimate the gas consumption and emission volumes of three types of criteria pollutants, carbon monoxide (CO), nitrogen oxides (NO_x), and exhaust PM2.5, from the new vehicles' monthly usage at various scenarios. Gas consumption is given by,

$$GAS_{mt} = \sum_{j \in J_{mt}} (q_j \cdot \frac{Mileage_m}{FE_j}),$$

where J_{mt} is the set of models sold in market m at time t, q_j is the total sales of vehicles of model j, $Mileage_m$ is the monthly average travel distance of a local driver in the market m,[16] and FE_j is fuel efficiency (100km/liter). Comparing gas consumption at various scenarios to that in the null scenario, the changes in gas consumption are given by,

$$\begin{aligned} \Delta GAS_{mt} &= \sum_{j \in J_{mt}} (q_j^i \cdot \frac{Mileage_m}{FE_j} - q_j^0 \cdot \frac{Mileage_m}{FE_j}) \\ &= Mileage_m((Q_i - Q_0) \sum_{j \in J_{mt}} \frac{1}{FE_j} \tilde{s}_j^0 + Q_i \sum_{j \in J_{mt}} \frac{1}{FE_j} (\tilde{s}_j^i - \tilde{s}_j^0)), \end{aligned}$$

where, Q_i and Q_0 are the total sales in the i^{th} and null scenarios, respectively; $\tilde{s}_j^i$ and $\tilde{s}_j^0$ are the market shares of product j conditional on purchase in the i^{th} and null scenarios, respectively. The first part of the right-hand side of this equation measures the changes in gas consumption due to the sales increase, while

[16] We obtained the data of the monthly average travel distance from a 2005 survey by SINOTRUST, which is a leading marketing research institute in China. In this survey, they collected demographic and behavioral data of 406 passenger vehicle drivers in five cities, including Beijing and Shanghai. The average monthly travel distances are 1,479 km and 1,499 km in Beijing and Shanghai, respectively. The consumers' driving patterns could change over time. This would only scale up or down the difference of emissions across scenarios, but would not influence the order of emission volumes.

the second part describes the changes in gas consumption due to the market share weighted fuel efficiency changes.

The emission volumes of pollutants are given by,

$$EM_{lmt} = (\sum_{j \in J_{mt}} q_j) \cdot Mileage_m \cdot ue_l,$$

where, ue_l is the emission of pollutant l per kilometers listed in the below table.[17]

	Exhaust CO	Exhaust NO_X	Total Exhaust PM
g/mile	1.2141	0.0264	0.0039
g/km	0.7544	0.0164	0.0024

Table 7 shows the monthly gas consumption and emission volumes of these pollutants from the new vehicles sold in Beijing and Shanghai in June 2010 in various scenarios. The license fee reduces gas consumption 47.67% for Shanghai and 47.21% for Beijing in terms of the gas consumption in the scenario without a license fee. By decomposing the changes in gas consumption, we find that vehicle control caused by the license fee would have reduced gas consumption 49.09% in Shanghai and 47.68% in Beijing without the counter effect from lower fleet efficiency, which actually increased gas consumption by 1.42% in Shanghai and 0.47% in Beijing.

The license fee also downsizes most pollutants to almost half their volume without license fee. Although it seems the pollution reduction is not significant in magnitude, the total reduction could be dramatic given that the national sales are much larger than the monthly city-level sales, and even larger when we consider the deduction from the lifetime usage of the vehicles.

[17]Currently, vehicles in China follow different exhaust emission standards, which affect the measurement of emission volume. The Ministry of Environmental Protection of the People's Republic of China published the limits and measurement methods for emissions of pollutants from light vehicles in 2001. From then on, all new vehicles must follow Euro I emission standards. The standards were upgraded to the Euro II on July 1, 2004, and to Euro III on July 1, 2007. Euro IV standard took effect in 2010. At present, most vehicles adopt standards equivalent to Euro III or Euro IV petrol standards. We use the Mobile6 Vehicle Emission Modeling Software developed by the United States Environmental Protection Agency to generate the per mile emissions of the pollutants in the table, and then translate them into per kilometer emissions.

7.3 Alternative policy

Despite the VQS's effectiveness in controlling the vehicle population and reducing air pollution, it has been subject to criticism for the following reasons. First, the license fee costs almost as much as the average annual income in Shanghai during 2009 and 2010. Low-income consumers cannot afford the license fee on top of a car, so they blame the system for being unfair since it is likely to keep low-income people out of the car market. Second, the system conflicts with the central government policy as discussed earlier.

In this section, we examine other policy options that comply with the purpose of vehicle control, but also overcome the above criticisms. We simulate two scenarios: the first registration tax system of Hong Kong and an optimal tax rate, targeting to achieve the highest fuel efficiency at a given fleet size. The Hong Kong government applies the first registration tax to encourage the use of environmentally friendly petrol private cars with low emissions and high fuel efficiency. Unlike the VQS of Shanghai, the Hong Kong registration fee is not uniform but varies by vehicle price. Details of the tax system are listed in Table 9. This kind of tax system appears to resolve the fairness argument since its tax rate is progressive in vehicle prices. Similarly, a regressive tax in fuel efficiency (or equivalently, a progressive tax in fuel consumption) could serve the environment-friendly purpose better. We design such a tax, assuming the tax rate is a linear function of fuel consumption, $t = a + b * FC$. If $b > 0$, the tax rate for a gas-guzzler will be higher than the tax rate for a fuel efficient vehicle, which will switch the demand to the fuel efficient vehicles. To get the optimal tax rates, we set the target fleet size to be the same as that under vehicle quota in Shanghai, and the revenue from the tax is no less than that from the quota since the government may use the revenue to improve the public transportation; then, we search for a, b to minimize the predicted fleet consumption in Shanghai. The estimates of a and b are 0.0631 and 0.0291, respectively.

We check their effectiveness by simulation. Applying the Hong Kong tax system to Beijing and Shanghai and the optimal tax to Shanghai, we predict their effects on vehicle sales, gas consumption, and emissions of pollutants. The results are presented in Table 10. It shows that the Hong Kong tax system is as effective as the VQS in that the total sales in both Beijing and Shanghai are very similar to those under the VQS. Comparing fleet efficiency under these two systems, however, we observe that consumers tend to purchase more fuel efficient vehicles under the tax system, leading to a 7% or 6% increase in fleet efficiency for Shanghai or Beijing, respectively. Gas consumption and pollutant emissions are also lower under the tax system. From the government's perspective, such a tax system could bring as much revenue as the VQS does, so replacing the VQS with the tax system will not reduce the fiscal income necessary to support the public transportation system.

Under the optimal tax scheme, fleet efficiency is higher than under the quota system, while fleet size remains the same. This difference in fleet efficiency further lowers gas consumption by 11.52 billion liters. The emission of pollutants does not decline, since the emission calculation is independent of fleet efficiency. Since the government revenue does not change, such a tax scheme will not undermine the ability of the government to operate public transportation. In conclusion, a tax system with a progressive tax rate could be a good substitute for the VQS in Shanghai.

8 Conclusion

This paper investigates the environmental impact of the unique vehicle quota policy of Shanghai, China. Empirical findings suggest that, conditional on purchase of the license quota, consumers tend to purchase high-end vehicles with less fuel efficiency since the customers who can afford the license quota are less price sensitive. Hence, this policy is effective in vehicle control but lowers fleet efficiency.

The vehicle quota system is effective in emissions control, however our counterfactual analyses show that the quota policy is not as effective as some progressive tax policies, such as the first registration tax of Hong Kong or the designed optimal tax scheme, in reducing emissions. This suggests that the Shanghai government has alternative options to the current quota policy to control gas consumption and air pollution.

We also find that the local intrinsic preference for vehicles is higher in Beijing than in Shanghai, and this is the major driver of much higher vehicle sales and emissions in Beijing. The most likely reason lies in the poor state of the public transportation system in Beijing. Such findings suggest that quota system can only control the short-run demand for vehicles, but it cannot switch potential demand to public transportation without changing consumers' intrinsic preferences by, for example, improving the conditions of the public transportation system.

Currently, more Chinese cities have started to adopt the license quota policy. Most local governments agree on the effectiveness of quotas on vehicle control. The debate only lies in the allocation method: auction versus lottery. However, our study suggests that more options exist beyond the quota; moreover, the fundamental feature of an ideal policy is to lower the demand for private vehicles by improving the conditions of alternative modes of transportation.

Appendix

A1: Product segments

This section introduces the definition of product segments. We divide the vehicles into five segments in the conventional way of the Chinese auto industry. In terms of features and functions, there are three types of vehicles: sedan, Sport Utility Vehicle (SUV) and Multi-Purpose Vehicle (MPV). For each type, the manufacturers usually define segments based on the length of the vehicles as shown in Table 11. We aggregate the parallel segments of different types, and name them as mini, small, intermediate, large, and luxury vehicles. The statistics of some features for each segment are listed in Table 11. It shows that the mean prices and features are quite different across segments.

A2: Demographic data

Consumers with different incomes usually have heterogeneous preferences, so we need to control for income. Unfortunately, we do not have individual-level income data. From Shanghai/Beijing Statistical Yearbook, we can obtain the mean of each quantile of the annual income distribution. Following BLP (1995), we assume the income distribution to be lognormal; then, we estimate the standard deviation and mean of the lognormal distribution in the following way: first, we randomly draw $10,000$ samples from the lognormal distribution with standard deviation a and mean b. Second, we compute the sample mean and the mean of each quantile of the simulated sample, and the sum of squares of the difference between the simulated and actual means. Third, we search for the optimal a and b that minimize this summation for each metropolitan city in each year. The simulated individual incomes are randomly drawn from the distribution with the optimal parameters.

According to the China Household Finance Survey in 2011, less than 10% of car consumers get a car loan,[18] which means most consumers use their savings to purchase a car. Hence, the feasible choice set is subject to the consumers' budget constraint. We assume that a consumer i can only afford a car j with price, p_j, no greater than her savings, $Savings_i$. If $Savings_i < p_j$, then product j is not in the feasible set of

[18] In contrast, this number is up to 70% in the United States.

consumer i. In the other words, the feasible set of consumer i is the set of products: $\{ j \mid Savings_i > p_j \}$. We assume the savings of consumer i is proportional to her income y_i given by,[19]

$$Savings_i = y_i \cdot AverageFamilySize \cdot \frac{AverageSavings_{mt}}{AverageIncome_{mt}}.$$

Both the average family size, $AverageFamilySize$, and the average saving ratio, $\frac{AverageSavings}{AverageIncome}$, are collected from Shanghai / Beijing Statistical Yearbook.

[19] In this way, the consumers are actually defined as households.

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Table 1: Comparison of Characteristics in Beijing and Shanghai in 2010

Variables	Beijing	Shanghai
Average annual income of urban residents (RMB)	29,073	31,838
Number of households in selected districts	6,664,336	6,295,784
Average number of people in a household	2.8	2.9
Average savings	90,808	76,933
Average savings/income	3.35	2.58
Area (square kilometers)	16,410.54	6,340.5
Length of operating urban metro lines (km)	336	452.57
Passenger vehicle population	4,257,377	1,462,431

Note: The above data are from Beijing / Shanghai Statistical Yearbook or census.

Table 2: Summary Statistics

Variables	mean	std	p10	p25	p50	p75	p90	Observations
Model level								
Price (RMB)	155,350	130,386	4,9900	76,069	108,800	183,767	329,800	484
Width (cm)	1,754	86.09	1,645	1,695	1,765	1,820	1,822	484
Length (cm)	4,461	410.5	3,890	4,264	4,531	4,762	4,981	484
Fuel efficiency (100km/liter)	0.1260	0.0250	0.0943	0.1087	0.1250	0.1408	0.1538	484
Horsepower (kw)	98.58	35.51	63	76	90.40	118	147	484
Luxury	0.136	0.344	0	0	0	0	1	484
Large	0.0537	0.226	0	0	0	0	0	484
Medium	0.424	0.495	0	0	0	1	1	484
Small	0.310	0.463	0	0	0	1	1	484
Mini	0.0764	0.266	0	0	0	0	0	484
Model-market-time level								
Sales per market (units)	128.6	200.9	9	17	48	153	358	10,534

Note: A geographic market is defined as a province / metropolis, while time is a month.

Table 3: Correlation of Variables

	Price	Height	Width	Length	Fuel efficiency	Horsepower	Sales	Observations
Price	1							10,534
Width	0.624	0.196	1					10,534
Length	0.602	0.131	0.809	1				10,534
Fuel efficiency	-0.609	-0.330	-0.737	-0.734	1			10,534
Horsepower	0.840	0.0935	0.748	0.711	0.721	1		10,534
Sales	-0.0687	-0.145	0.00840	0.0571	-0.103	-0.0598	1	10,534

Table 4: Results for Demand Estimation

	Logit	Nested logit	Nested logit	Random coefficient nested logit
Model	(i)	(ii)	(iii)	(iv)
Within-segment correlation	No	Yes	Yes	Yes
IVs	No	No	Yes	Yes
Budget constraint	No	No	No	Yes
Explanatory variable				
Segments (σ)	-	0.6342***	0.6238***	0.6084***
	-	(0.0053)	(0.0088)	(0.0088)
Total price (thousand RMB in 2010)	-0.0019***	-0.0048***	-0.0131***	-
	(0.0002)	(0.0001)	(0.0003)	-
ln(savings - total price)	-	-	-	3.8099***
	-	-	-	(0.2456)
Width (m)	1.8021***	2.7625***	2.3782***	3.6176***
	(0.2884)	(0.1877)	(0.2256)	(0.2556)
Length (m)	0.9860***	0.9804***	0.9576***	1.0474***
	(0.0550)	(0.0358)	(0.0430)	(0.0430)
Fuel efficiency (100km/liter)	12.6551***	11.2755***	8.0112***	8.6041***
	(0.8355)	(0.5434)	(0.6585)	(0.6554)
Horsepower (kw)	-0.0041***	0.0033***	0.0277***	0.0238***
	(0.0008)	(0.0005)	(0.0009)	(0.0010)
Dummy for a Shanghai brand	0.8328***	0.5216***	0.2760***	0.3611***
sold in Shanghai	(0.0467)	(0.0305)	(0.0375)	(0.0333)
Dummy for a Beijing brand	0.1261**	-0.0109	0.1142**	0.1492***
sold in Beijing	(0.0551)	(0.0359)	(0.0431)	(0.0431)
Dummy for the year of 2010	0.0834***	0.1760***	0.1353***	0.2409***
	(0.0230)	(0.0150)	(0.0180)	(0.0176)
Dummy for American cars	-0.0600	-0.2435***	-0.0349	0.0088
	(0.0608)	(0.0396)	(0.0477)	(0.0370)
Dummy for European cars	0.2815***	0.2331***	0.8770***	0.9247***
	(0.0576)	(0.0374)	(0.0476)	(0.0400)
Dummy for Japanese cars	0.3649***	0.0598	0.2151***	0.2928***
	(0.0567)	(0.0369)	(0.0445)	(0.0352)
Dummy for domestic cars	-0.7431***	-0.7785***	-0.7814***	-0.9122***
	(0.0547)	(0.0356)	(0.0427)	(0.0354)
Dummy for Beijing	1.0676***	1.2531***	0.9094***	0.6225***
	(0.0282)	(0.0184)	(0.0233)	(0.0279)
Observations	10,534	10,534	10,534	10,534
R^2	0.258	0.686	0.547	-

Note: The five segments are mini, compact, intermediate, standard, and luxury.
Total price is defined as the sum of price and average license fee.
Dummy for 2009, dummy for Korean cars, and dummy for Beijing are omitted.
Numbers in parentheses are standard deviations.
Asterisks indicate significance at 10% (*), 5% (**) and 1% (***) or better.
Month dummy variables are also included.

Table 5: Summary of Price Elasticities (Model (iv))

Own-price elasticities	
Mean	-5.3553
25% quantile	-5.6711
Median	-5.1280
75% quantile	-4.0971
Cross-price elasticities	
Mean	0.0129
25% quantile	0.00001
Median	0.00008
75% quantile	0.0040

Table 6: Differences of Car Models Sold in Beijing and Shanghai in June 2010

	Common	Only in Beijing	Only in Shanghai
Number of models	214	93	2
Average price (RMB in 2010)	156,511	132,668	329,300
Ratio of models of indigenous brands	0.2336	0.6237	0
Ratio of models manufactured in Shanghai	0.2477	0.0323	0
Ratio of models manufactured in Beijing	0.0748	0.0968	0

Table 7: Counterfactual Analysis of Car Sales in Shanghai in June 2010

	Shanghai		Beijing			
Scenarios	Null	(i)	Null	(ii)	(ii')	(ii")
License price (RMB in 2010)	40,380	0	0	40,380	85,507	48,063
Sales	11,381	22,057	43,080	22,540	11,381	20,000
Sales weighted average price (RMB in 2010)	170,014	161,555	145,500	153,400	163,499	155,029
Sales weighted average fuel efficiency (100km/liter)	0.1204	0.1219	0.1296	0.1286	0.1273	0.1284
Mean of income of car buyers (RMB in 2010)	72,399	62,659	49,020	56,750	66,142	58,294
Gasoline consumption (billion liters)	146.5773	280.1060	504.0634	266.1165	135.8734	236.5784
Total change in gasoline consumption (billion liters)	-	133.5288	-	-237.9469	-368.1900	-267.4850
Change in gasoline consumption (billion liters) due to change in sales	-	137.5044	-	-240.3296	-370.8904	-270.0304
Change in gasoline consumption (billion liters) due to change in fuel efficiency	-	-3.9756	-	2.3827	2.7003	2.5454
Exhaust CO (ton)	12.8690	24.9465	48.0668	25.1492	12.6981	22.3152
Exhaust NO_X (ton)	0.2798	0.5423	1.0449	0.5467	0.2760	0.4851
Total Exhaust PM (ton)	0.0410	0.0794	0.1529	0.0800	0.0404	0.0710

Note: Scenario (i) is the case that no license fee is collected in Shanghai; Scenario (ii) is the case that the same license fee as that of Shanghai is collected in Beijing. Scenario (ii') is the case that the same quota as that of Shanghai is imposed in Beijing. Scenario (ii") describes the case that the quota is 20,000 per month, the same as the reality of Beijing.

Table 8: CAFC Standards and Simulated Values for Top 10 Auto Firms in June 2010, Shanghai

		License fee				No license fee			
	Ratio of cars with manual transmission in Shanghai	Sales	CAFC	Target CAFC of 2012	Distance of CAFC to target	Sales	CAFC	CAFC target of 2012	Distance of CAFC to target
Shanghai Volkswagen	0.5818	2,547	8.3595	8.0671	0.2924	5,003	8.3096	8.0202	0.2894
Shanghai GM	0.3077	2,247	8.8944	8.7823	0.1120	4,373	8.7809	8.7026	0.0783
First Auto Volkswagen	0.1758	1,064	9.5576	9.0009	0.5566	1,913	9.2313	8.8906	0.3407
Dongfeng Nissan	0.0765	693	8.1263	8.1476	-0.0214	1,334	8.0317	8.0753	-0.0435
Changan Ford	0.2856	507	8.3977	8.1351	0.2626	1,012	8.3130	8.0896	0.2234
First Auto Toyota	0.1052	453	8.5444	8.6837	-0.1393	818	8.4559	8.6192	-0.1633
Guangzhou Honda	0.1534	388	8.3198	8.5238	-0.2039	725	8.2641	8.4902	-0.2261
Dongfeng Honda	0.1220	426	8.3695	8.7507	-0.3812	768	8.3185	8.7099	-0.3914
Shanghai Auto	0.2528	360	9.1233	8.4072	0.7161	743	9.1023	8.3872	0.7151
Guangzhou Toyota	0.0501	397	9.9065	9.3201	0.5864	701	9.8687	9.2840	0.5847

Note: Top 10 auto firms are in terms of sales in China in 2010.
Since even for the same model, a consumer has the option of manual or nonmanual transmission, we assume that the ratio of manual transmission for a given firm does not change under any counterfactual analysis.

Table 9: First Registration Tax Rate in Hong Kong

Class of motor vehicle	Rate of tax
a. the first HKD150,000 of taxable value	40%
b. on the next HKD150,000	75%
c. on the next HKD200,000	100%
d. on the remainder	115%

Source: The Transport Department, The Government of the Hong Kong Special Administrative Region.
Note: 100 HKD was about 88 RMB on January 1, 2010.
1 USD was about 6.82 RMB on January 1, 2010.

Table 10: Counterfactual Analysis for The First Registration Tax of Hong Kong and Optimal Tax Rate in June 2010

	Previously in Beijing (Baseline)	Adding license fee of Shanghai to Beijing	Adding tax rate as Hong Kong to Beijing	Previously in Shanghai (Baseline)	Adding tax rate as Hong Kong to Shanghai	Adding optimal tax rate to Shanghai
Sales of cars sold	43,080	22,540	20,200	11,381	8,909	11,381
Sales weighted price of cars sold (RMB in 2010)	145,500	153,400	105,200	170,014	123,400	132,970
Sales weighted fuel efficiency of cars sold (100km/liter)	0.1296	0.1286	0.1362	0.1204	0.1292	0.1292
Mean of income of car buyers (RMB in 2010)	49,020	56,750	45,000	72,399	65,630	64,926
Gasoline consumption (billion liters)	504.06	266.12	224.03	146.5773	105.75	135.0609
Total change in gasoline consumption (billion liters)	-	-237.9469	-280.0335	-	-40.8306	-11.5163
Change in gasoline consumption (billion liters) due to change in sales	-	-240.3296	-267.7003	-	-31.8358	0
Change in gasoline consumption (billion liters) due to change in fuel efficiency	-	2.3827	-12.3332	-	-8.9948	-11.5163
Exhaust CO (ton)	48.0668	25.1492	22.5383	12.8690	10.0747	12.8690
Exhaust NO_X (ton)	1.0449	0.5467	0.4900	0.2798	0.2190	0.2798
Total Exhaust PM (ton)	0.1529	0.0800	0.0717	0.0409	0.0321	0.0409
Revenue of license fee / tax (million RMB in 2010)	0	910.1	911.9	459.5	475.8	459.5

Note: The optimal tax rate is a linear tax that is a two-tariff tax.

The optimal tax rate is 0.0631+ 0.0291*fuel consumption, where fuel consumption = 1/fuel efficiency.

It achieves the lowest level of average fuel consumption, under the two constraints :

(1) total car sales is no greater than current sales;

(2) total tax revenue is no less than current revenue of license fee.

Table 11: Vehicle segments and statistics

	Segments based on vehicle length (m)			Segment Mean			
	Sedan	SUV	MPV	No. of observations	Price (RMB yuan)	Displacement (liter)	Weight (kg)
Mini	<4.00	<4.00		37	45335.65	1.16	969.24
Small	4.00-4.20	4.00-4.30	<4.10	149	93942.94	1.62	1238.53
Intermediate	4.20-4.45	4.30-4.60	4.10-4.20	206	140166.40	1.88	1393.37
Large	4.45-4.80	4.60-5.00	4.20-4.60	26	153662.00	2.30	1817.46
Luxury	>4.80	>5.00	>4.6	66	417085.60	2.63	1751.92

Figure 1: The Price and Quota of Private Car License Plates in Shanghai

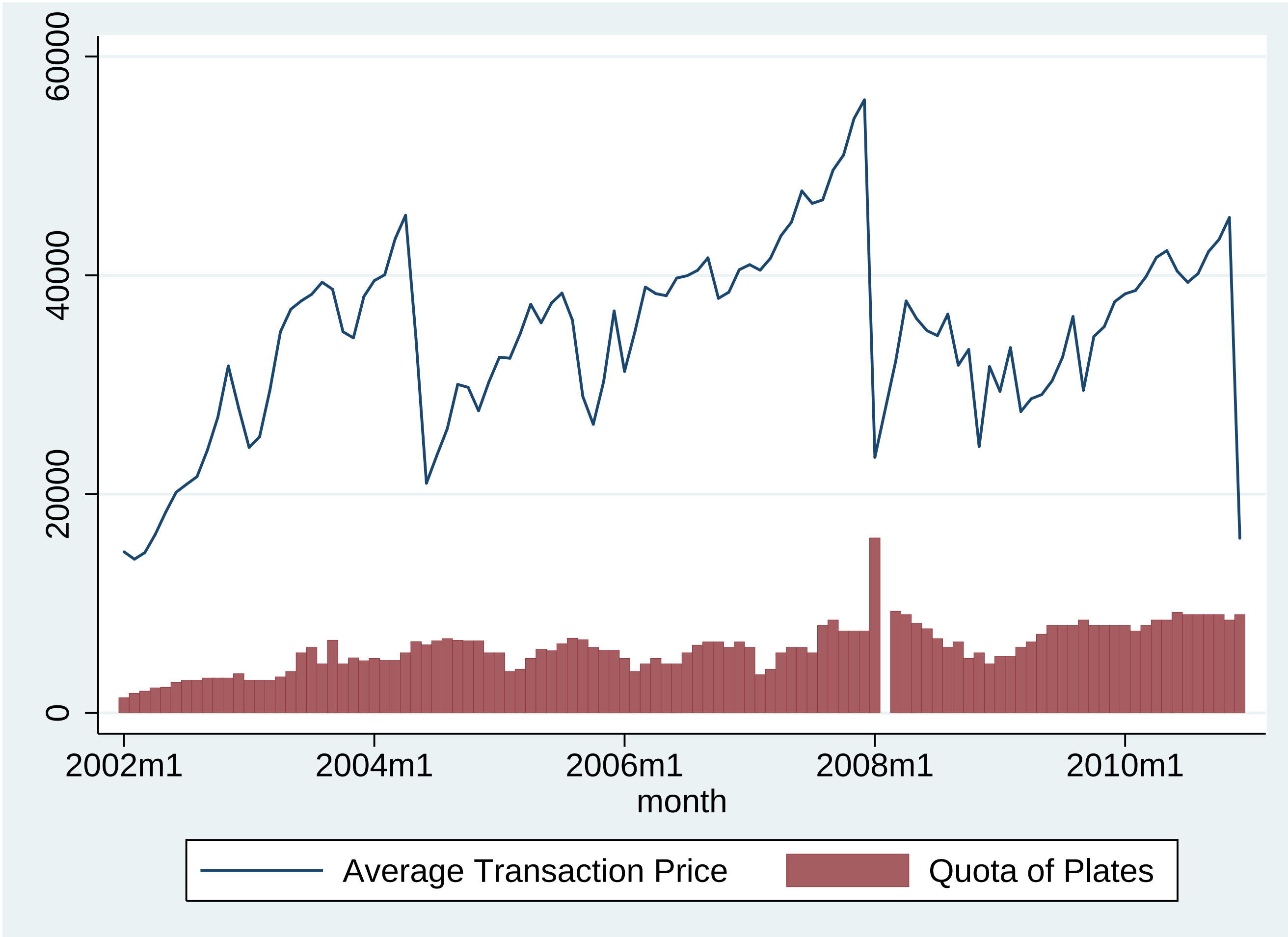


Figure 2: Fuel Efficiency Distribution of Shanghai versus Other Provinces

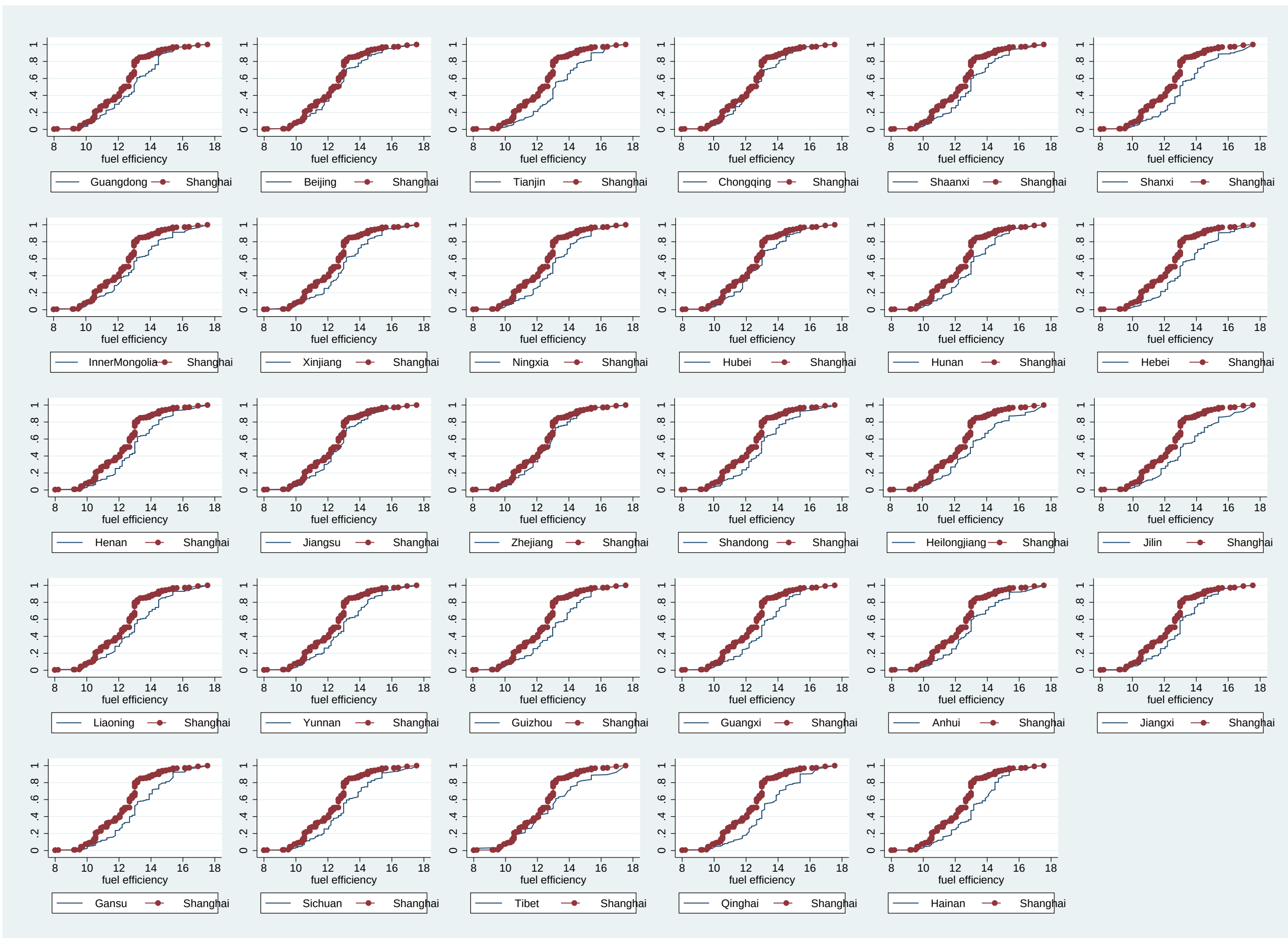
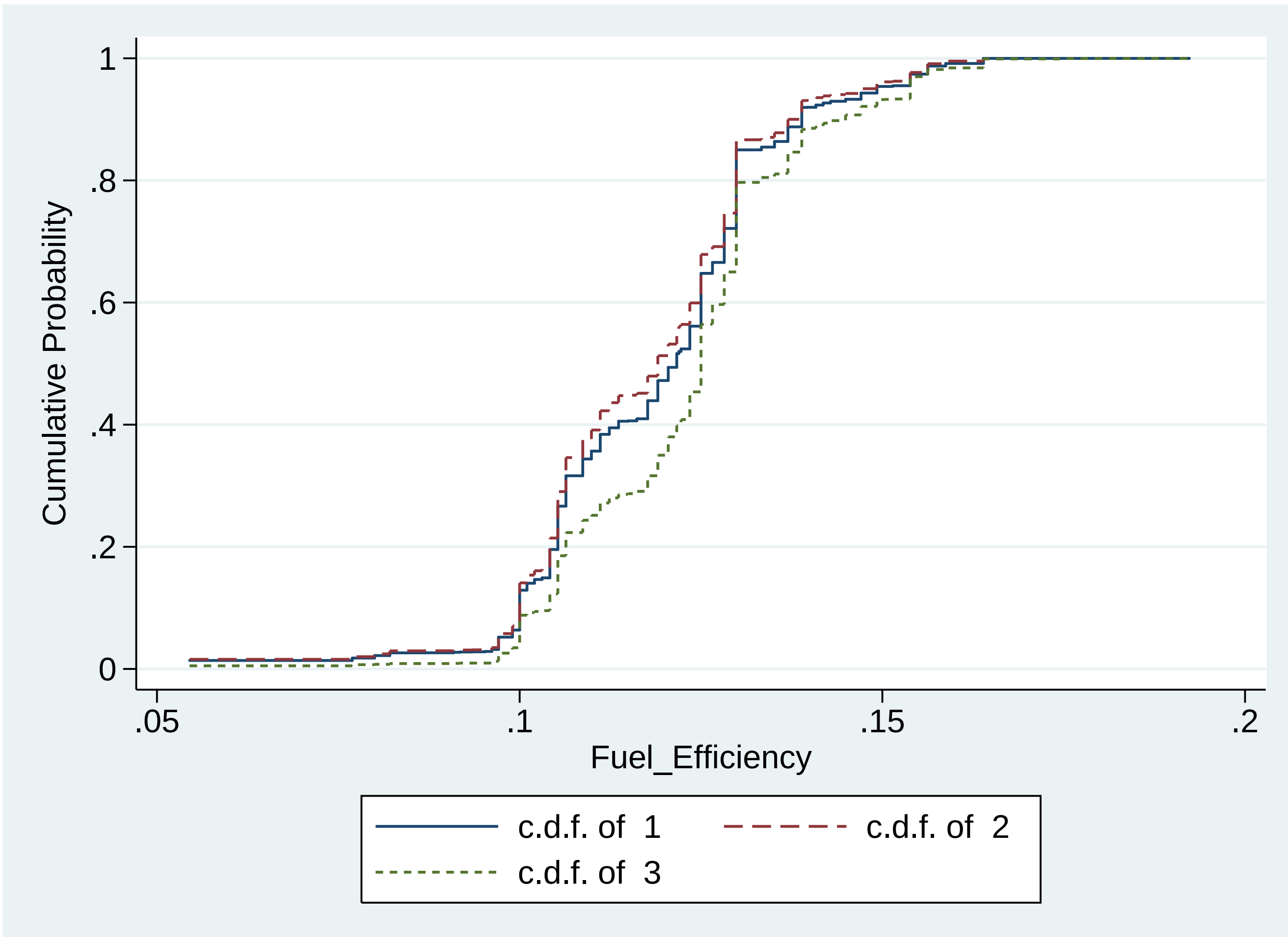


Figure 3: The Simulated Cumulative Distribution Functions of Fuel Consumption of Cars without License Fee



Note: 1 stands for fuel inefficiency distribution of cars bought by current buyers in Shanghai (benchmark);
2 stands for fuel inefficiency distribution of cars bought by current buyers in Shanghai if there is no license fee;
3 stands for fuel inefficiency distribution of cars bought by the people who do not buy a car but would
if there were no license fee in Shanghai.