The Chinese Automobile Industry and Government Policy[1]

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Abstract

China is experiencing rapid economic growth and, along with it, rapid growth in vehicle ownership. The rapid growth in vehicle ownership and vehicle usage is linked to increasing global warming, emissions, air pollution, and other problems. In this paper, we discuss the Chinese automobile industry and government policy; review the literature on automobile supply, demand, and policy; and describe the characteristics of vehicles in the Chinese automobile industry. We also review our work in Chen et al. (2017), in which we analyze the supply and demand for automobiles in China, and the effects of government policy on the supply and demand for alternative vehicles.

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1. Introduction

China is experiencing rapid economic growth and, along with it, rapid growth in vehicle ownership. Evidence from Chinese cities suggests average annual growth rates in per capita vehicle ownership of 10% to 25% (Darido, Torres, and Mehndiratta, 2014). According to data from the China Statistical Yearbook, vehicle ownership increased by nearly 56 times between 1990 and 2011. The rapid growth in vehicle ownership and vehicle usage is linked to increasing global warming, emissions, air pollution, and other problems.

In this paper, we discuss the Chinese automobile industry and government policy; review the literature on automobile supply, demand, and policy; and describe the characteristics of vehicles in the Chinese automobile industry. We also review our work in Chen et al. (2017), in which we analyze the supply and demand for automobiles in China, and the effects of government policy on the supply and demand for alternative vehicles.

2. China's Automobile Industry

In 2009, China's automobile market became the largest in the world, surpassing the U.S. automobile market both in sales and production. The annual gross product of the China's automobile industry has exceeded 5% of the country's annual GDP every year since 2002, and was as high as 7.4% of its GDP in 2010.[2]

The Chinese automobile industry underwent several phases of growth since the start of China's economic reform in 1978. At that time, automobile manufacturing was very low in productivity. In the year 1980, total vehicle output was around five thousand vehicles only. As

[2] These statistics were calculated using GDP data from the National Bureau of Statistics of China and automobile industry gross product data from Chinese Automobile Industry Yearbook.

incomes grew, household demand for passenger vehicle grew rapidly, which resulted in a large amount of cars being imported to China. In order to protect the vulnerable and immature domestic Chinese automobile industry, tariffs were set as high as 250% (Li, Xiao and Liu, 2015).

Several large state-owned automobile enterprises in China tried to partner with foreign auto manufacturers to form joint ventures to increase their capacity and enhance their technical capabilities. However, foreign ownership was capped at 50% to protect domestic producers. In 1994, China's National Development and Reform Commission (NDRC) initiated an automobile industry policy encouraging state-owned firms to partner with international car makers to form joint ventures (Li, Xiao and Liu, 2015). Following this policy, more joint ventures were formed between large state-owned automobile companies and foreign auto manufacturers (Li, Xiao and Liu, 2015). Meanwhile, local and private producers also entered the market.

In 2001, China entered the World Trade Organization (WTO). In order to fulfill its commitment under the WTO, the Chinese government gradually cut the tariffs on foreign automobiles from 100% to 25% during the 5-year transition period. However, the market shares of imports further dropped from about 6% in 2001 to 3% in 2006 and it has stayed at that level since then (Li, Xiao and Liu 2015).

The Chinese manufacturers of passenger vehicles can be categorized into two different types: indigenous-brand manufacturers, such as BYD, Geely, and Chery; and joint ventures between domestic manufacturers and foreign manufacturers, such as Shanghai Automotive Investment Company (BAIC) with Hyndai, and Dongfeng with Honda.

In Figure 1, adapted from Hu, Xiao and Zhou (2014), we present the market structure of the Chinese automobile industry. The car makers in large boxes are the top state-owned automobile groups in China. The ones in small isolated boxes at the bottom are indigenous local makers.

According to Chinese automobile policy, a Chinese automobile company can form joint ventures with multiple foreign car manufacturers. For example, Shanghai Auto has cooperated with General Motors and Volkswagen. Dofeng Motors partners with Nissan, Kia, and PSA. On the other hand, under Chinese policy, a foreign car manufacturer is only allowed to form joint ventures with up to two Chinese automobile companies.[3] For example, Honda partners with both Donfeng Group and Guangdong Auto. Toyota, another Japanese automobile firm, cooperates with both Fist Auto Work and Guangdo Auto. Besides large stated-owned auto groups, private car makers also partner with foreign makers. Huachen Auto cooperates with BMW. Joint ventures with international car companies account for two thirds of the passenger vehicle market, with the rest mostly taken up by indigenous brands (Li, Xiao and Liu, 2015).

Figure 2 presents the location of the automobile firms listed in Figure 1. Most of the automobile firms are located along the east of the continent. Two of the "China Automobile Group Four" are located in the east, with First Auto Work in the northeast, and Shanghai Automotive Investment Company (SAIC) in the Southeast. For the other two, Dongfeng Group is in the middle east of the country, while Chang'an Automobile Group is in central China. Two large indigenous firms Geely and Chery are located in the southeast part of China.

In 2005, CAAM, the statistical organization of the Chinese automobile industry that categorizes vehicles, reclassified vehicles into two broad categories: passenger vehicles and commercial vehicles. CAAM further divided passenger vehicle into four categories: Basic Passenger Vehicle (BPV), Sports Utility Vehicle (SUV), Multi-purpose Vehicle (MPV), and others (such as crossovers). In 2012, according to the China Automobile Industry Year Book, the

[3] According to "Chinese Automobile Industry Development Policy, 2009 edited edition". *http://www.china.com.cn/policy/txt/2009-08/31/content_18430768_5.htm*

total Basic Passenger Vehicle (BPV) output is 10.767 million and that for Multi-purpose Vehicle (MPV) and Sports Utility Vehicle (SUV) is 491.896 thousand and 1.999 million respectively. The total output and sales for passenger vehicle in 2012 is 13.258 million and 13.239 million, respectively.

According to China's National Bureau of Statistics, from 2004 to 2014, the total number of civil passenger vehicles owned in China increased from 17.35 million to 123.27 million, with an annual growth rate of 21.69%. The total number of civil vehicle owned in China, including civil trucks, was 145.98 million in 2014.

In September 2004, China introduced its first fuel economy standards for light duty passenger vehicles (GB 19578-2004), targeting a fuel consumption of 6.9 L/100km by 2015, which translates to an estimated 167 g/km of CO_2 emissions. The standards were initially outlined in two phases with different national standards of "limits of Fuel Consumption of Passenger Cars". The national standard limits are set for 16 categories of curb weights and also differentiates manual transmission from automatic transmission.

The first phase began in July 2005 for new vehicle production, and a year later for existing vehicle production. Phase 2 began in January 2008 for new vehicle production, and full segment production compliance was implemented in 2009.

The cars initially included in the fuel economy standard were passenger cars, SUVs, and light commercial vehicles (LCVs). These vehicles are collectively defined as M1-type vehicles by the EU, and are defined in the Chinese standard as vehicles with a minimum speed of 50 km/h and a maximum weight of 3500 kg.

The third phase of the passenger vehicle fuel economy standard includes Corporate Average Fuel Consumption (CAFC) target (GB 27999-2011), which went into effect in 2012 and is intended to bind in 2015. Together with the passenger car fuel limits standard (GB 19678-2004), CAFC is designed to realize an ambitious average fuel consumption target of 6.9 L/100km by 2015. The fourth phase recently released is providing gradual implementation guidelines towards a 2020 5.0 L/100km binding target.

The CAFC uses vehicle model, year, and annual sales to calculate the following weighted average for fuel consumption based on the New European Driving Cycle (NEDC):

$$CAFC = \frac{\sum_i FC_i \cdot V_i}{\sum_i V_i} ,$$

where FC_i is the fuel consumption of model *i* and V_i is the annual sales of model *i*.

The government sets higher weights for alternative fuel vehicles to encourage their production. Until 2015, in the CAFC calculation, a multiplier of 5, 5, 5, 3 of the quantity sales are used for pure-electric, fuel-cell electric, plug-in hybrid, and energy saving vehicles respectably. The weights gradually decrease thereafter.[4] Table 1 presents the multipliers imposed on the annual sales/imports of alternative fuel vehicles in the CAFC calculation.

The CAFC target T_{CAFC} is based on individual vehicle fuel consumption targets, which use the quantity of annual sales of each model to calculate a weighted average as follows:

$$T_{CAFC} = \frac{\sum_i T_i \cdot V_i}{\sum_i V_i},$$

where T_i is the fuel consumption target of model *i* and V_i is the annual sales of model *i*.

[4] 2015 annual report of Chinese passenger vehicle fuel consumption 2015 by Innovation Center for Energy and Transportation

The national standard (GB 27999) target implementation status is indicated by $\frac{CAFC}{T_{CAFC}}$.

The CAFC requirement was enacted in 2012 and allows automobile manufacturers until 2015 to gradually reduce the fuel consumption levels (3% each year), towards the CAFC binding period starting in 2015 (100% compliance).

In addition to fuel economy standards, in 2010 the Chinese government established a project called "energy saving projects", which uses a fiscal subsidy to encourage energy saving. Some autos with low displacement (less than 1.6L) will receive a subsidy (directly to the car makers) such that the market price is the price after subsidized.[5]

3. Literature Review

In this section, we review several strands of related literature on automobile supply, demand, and policy.

3.1. Structural econometric models of automobile demand and supply

The first strand of literature we review is that on structural econometric models of automobile demand and supply. Goldberg (1995) develops and estimates a model of the U.S. automobile industry. On the demand side, a discrete choice model is estimated using micro data from the Consumer Expenditure Survey. The estimation results are used in conjunction with population weights to derive aggregate demand. On the supply side, the automobile industry is modeled as an oligopoly with differentiation. Equilibrium is characterized by the first-order

[5] Announcement published by the Ministry of Finance of the People's Republic of China. http://jjs.mof.gov.cn/zhengwuxinxi/zhengcefagui/201006/t20100601_320724.html

conditions of the profit maximizing firms. The estimation results are used in counterfactual simulations to investigate two trade policy issues: the effects of the voluntary export restraint, and exchange rate pass-through.

Berry, Levinsohn and Pakes (1995) develop techniques for empirically analyzing demand and supply in differentiated products markets and then apply these techniques to analyze the equilibrium in the U.S. automobile industry. The framework they present enables one to obtain estimates of demand and cost parameters for a class of oligopolistic differentiated products markets, using only widely available product-level and aggregate consumer-level data, which are consistent with a structural model of equilibrium in an oligopolistic industry.

Petrin (2002) develops a technique useful for obtaining more precise estimates of demand and supply curves when constrained to market-level data. The technique augments the estimation routine with data on the average characteristics of consumers that purchase different products. He applies his technique to the automobile market, estimating the economic effects of the minivan introduction. He shows that the results obtained are meaningfully different from those yielded by the standard approaches. Benefits accruing to both minivan and non-minivan consumers are reported.

Berry, Levinsohn and Pakes (2004) show how rich sources of information on consumer choice can help to identify demand parameters in a widely used class of differentiated products demand models. In particular, they show how to use "second-choice" data on automotive purchases to obtain good estimates of substitution patterns in the automobile industry. They use their parameter estimates to make out-of-sample predictions about important recent changes in industry structure.

3.2. Vehicle demand

The second strand of literature we review is that on vehicle demand. Sallee, West and Fan (2016) measure consumers' willingness to pay for fuel economy using a novel identification strategy and high quality microdata from wholesale used car auctions. They leverage differences in future fuel costs across otherwise identical vehicles that have different current mileage, and therefore different remaining lifetimes. By seeing how price differences across high and low mileage vehicles of different fuel economies change in response to shocks to the price of gasoline, they estimate the relationship between vehicle prices and future fuel costs. Their data suggest that used automobile prices move one for one with changes in present discounted future fuel costs, which implies that consumers fully value fuel economy.

Anderson and Sallee (2016) present a simplified model of car choice that allows them to emphasize the relationships between fuel economy, other car attributes, and miles traveled. They focus on greenhouse gas emissions. Besides the main familiar conclusion that standards are substantially less efficient than a fuel tax, they make the points about the relative importance of rebound effect, on the effects of attribute-based policies, and the implications of behavioral biases.

Understanding demand in the new plug-in hybrid electric vehicle (PHEV) market is critical to designing more effective adoption policies. Sheldon, DeShazo and Carson (2016) use stated preference data from an innovative choice experiment to estimate demand for PHEVs relative to battery electric vehicles (BEVs) and to explore heterogeneity in demand for these vehicles. They find the gap between willingness to pay for PHEVs and their price premium over conventional vehicles is on the order of current subsidies, while that of BEVs is an order of magnitude larger. They use a latent class model to show PHEVs draw a different consumer segment into the market.

Deshazo, Sheldon and Carson (forthcoming) assess the performance of alternative rebate designs for plug-in electric vehicles. Based on an innovative vehicle choice model, they simulate the performance of rebate designs that vary in terms of vehicle technologies consumer income eligibility, and caps on the price of vehicles eligible for subsidies. They compare these alternatives in terms of 1) the number of additional plug-in electric vehicles purchased, 2) cost-effectiveness per additional vehicle purchase induced, 3) total program cost and 4) the distribution of rebate funding across consumer income classes. Using the stats quo rebate policy in California as a reference case, they identify two alternative types of designs that are superior along all performance criteria.

Li and Zhou (2015) examine the dynamics of technology adoption and critical mass in network industries with an application to the U.S. electric vehicle (EVs) market, which exhibits indirect network effects in that consumer EV adoption and investor deployment of public charging stations are interdependent. Using a data set of quarterly EV sales in 354 U.S. metro areas from 2011 to 2013, they quantify indirect network effects and simulate long-run market outcomes in each of the Metropolitan Statistical Areas (MSAs). Their analysis provides robust and significant evidence of indirect network effects in this market. Also their simulations show several different market equilibrium outcomes across the MSAs in the long run with a significant number of them exhibiting multiple equilibria and critical mass.

Holland, Mansur, Muller, and Yates (2016) combine a theoretical discrete-choice model of vehicle purchases, an econometric analysis of electricity emissions, and the AP2 air pollution model to estimate the geographic variation in the environmental benefits from driving electric vehicles. The second-best electric vehicle purchase subsidy ranges from \$2,785 in California to −\$4,964 in North Dakota, with a mean of −\$1,095. Ninety percent of local environmental externalities from driving electric vehicles in one state are exported to others, implying they may be subsidized locally, even when the environmental benefits are negative overall. Geographically differentiated subsidies can reduce deadweight loss.

The firm response to regulation is seldom as controversial as in the context of fuel economy standards, a dominant policy to reduce emissions from vehicles worldwide. It has long been argued that such standards lead to vehicle weight changes that increase accident fatalities. Using unconditional quantile regression, Bento, Gillingham and Roth (2017) are the first to document the effect of the Corporate Average Fuel Economy (CAFE) standards on the vehicle weight distribution. They find that on net CAFE reduced fatalities, with lowered mean weight dominating increased dispersion. When monetized, this effect suggests positive net benefits from CAFE even with no undervaluation of fuel economy.

3.3. The effects of government policy on vehicle demand

We also review the literature on the effects of government policy on vehicle demand, particularly for alternative vehicles.

Gallagher and Muehlegger (2011) study the relative efficacy of state sales tax waivers, income tax credits, and non-tax incentives to induce consumer adoption of hybrid-electric vehicles. They find that the type of tax incentive offered is as important as the generosity of the incentive. Additionally, they examine how adoption varies with fuel prices. By comparing consumer response to sales tax waivers and estimated future fuel savings, they estimate an implicit discount rate of 14.6% on future fuel savings.

Beresteanu and Li (2011) analyze the determinants of hybrid vehicle demand, focusing on gasoline prices and income tax incentives. They find that hybrid vehicle sales in 2006 would have been 37% lower had gasoline prices stayed at the 1999 levels, and the effect of the federal income tax credit program is estimated at 20% in 2006. Under the program, the cost of reducing gasoline consumption was $75 per barrel in government revenue and that of CO_2 emission reduction was $177 per ton. They show that the cost effectiveness of federal tax programs can be improved by a flat rebate scheme.

Sallee (2011) estimates the incidence of tax incentives for the Toyota Prius. Transaction microdata indicate that both federal and state incentives were fully captured by consumers. This is surprising because Toyota faced a binding production constraint, which suggests that they could have appropriated the gains. The paper proffers an explanation based on an intertemporal link in pricing that stems from search frictions, which has the unconventional implication that statutory burden influenced economic burden.

Jacobsen and van Benthem (2015) estimate the sensitivity of scrap decisions to changes in used car values and show how this "scrap elasticity" produces emissions leakage under fuel efficiency stands, a process known as the Gruenspecht effect. After first estimating the effect of gasoline prices on used vehicle values and scrappage of vehicles with different fuel economies, they then estimate the scrap elasticity itself, which they found to be -0.7. When applied in a model of fuel economy standards, 13-16 percent of the expected fuel savings leak away through the used vehicle market, which effect rivals or exceeds the importance of the often-cited mileage rebound effect.

3.4. Vehicle supply and the effects of government policy

We also review the literature on vehicle supply, and the effects of policies on vehicle supply.

Heutel and Muehlegger (2015) study the effect of differences in product quality on new technology diffusion. They propose a model in which heterogeneity in perceived product quality affects consumer adoption. If consumers experientially infer the quality of a technology, an increase in initial exposure to a low-quality product may inhibit subsequent diffusion. Incentives intended to speed up adoption may in fact have the opposite effect, if they propagate low-quality signals. They examine the predictions of the model using sales data for 11 hybrid-vehicle models between 2000 and 2006. They find that conditional on overall hybrid vehicle adoption in the first 2 years, locations with a relatively high Prius market share experienced faster subsequent adoption than states with a relatively high Insight market share.

Aghion et al. (2016) construct new firm-level panel data on auto industry innovation distinguishing between "dirty" (internal combustion engine) and "clean" (e.g., electric, hybrid, and hydrogen) patents across 80 countries over several decades. They show that firms tend to innovate more in clear (and less in dirty) technologies when they face higher tax-inclusive fuel prices. Furthermore, there is path dependence in the type of innovation (clean/dirty) both from aggregate spillovers and from the firm's own innovation history.

Using detailed vehicle specifications, Ullman (2016) analyzes the impact identifiable vehicle characteristics and technological progress has on fleet economy by vehicle type and class. The results suggest manufacturers will face a difficult task complying with the new footprint-based CAFÉ standards if compliance is met by only changing identifiable vehicle characteristics. He finds evidence that the stringent footprint-based standards create manufacturer incentive to increase vehicle size to lower the burden of compliance. This undermines the standards' potential to create expected fuel savings and lower emissions levels.

Miravete, Moral and Thurk (2016) estimate a discrete choice oligopoly model of horizontally differentiated products using Spanish automobile registration data to assess the degree to which vehicle emissions policies impact the automobile industry, focusing on the European market where diesels are popular. Their estimation uses changes in observed product characteristics to identify the underlying demand and cost parameters while allowing for correlation between observed and unobserved (to the researcher) product characteristics. They find that the EU emissions policy promoted diesel vehicles by setting weaker thresholds for the emissions produced by these vehicles. Further, diesels amounted to an important competitive advantage for European auto makers over foreign imports.

3.5. Vehicle supply and the effects of government policy

Another strand of literature is that on government policies related to vehicles.

Despite widespread agreement that a carbon tax would be more efficient, many countries use fuel economy standards to reduce transportation-related carbon dioxide emissions. Davis and Knittel (2016) pair a simple model of the automakers' profit maximization problem with unusually-rich nationally representative data on vehicle registrations to estimate the distributional impact of U.S. fuel economy standards. The key insight from the model is that fuel economy standards impose a constraint on automakers which creates an implicit subsidy for fuel-efficient vehicles and an implicit tax for fuel-inefficient vehicles. Moreover, when these obligations are tradable, permit prices make it possible to quantify the exact magnitude of these implicit subsidies and taxes. They use the model to determine which U.S. vehicles are most subsidized and taxed, and they compare the pattern of ownership of these vehicles between high- and low-income census tracts. Finally, they compare these distributional impacts with existing estimates in the literature on the distributional impact of a carbon tax.

Economists promote energy taxes as cost-effective. But policy-makers raise concerns about their regressivity, or disproportional burden on poorer families, preferring to set energy efficiency standards instead. Levinson (2016) first show that in theory, regulations targeting energy efficiency are more regressive than energy taxes, not less. He then provides an example in the context of automotive fuel consumption in the United States: taxing gas would be less regressive than regulating the fuel economy of cars if the two policies are compared on a revenue-equivalent basis.

Sallee and Slemrod (2012) analyze notches in fuel economy policies, which aim to reduce negative externalities associated with fuel consumption. They provide evidence that automakers respond to notches in the Gas Guzzler Tax and mandatory fuel economy labels by precisely manipulating fuel economy ratings so as to just qualify for more favorable treatment. They then describe the welfare consequences of this behavior and derive a welfare summary statistic applicable to many contexts. In brief, notches are an inefficient substitute for smooth policies because they create marginal incentives that vary among decision makers and induce some individual actions that have negative net social benefits.

Jacobsen (2013) employs an empirically estimated model to study the equilibrium effects of an increase in the US corporate average fuel economy (CAFE) standards. He identifies and models heterogeneity across firms and finds that the profit impacts of CAFE fall almost entirely on domestic producers. The welfare analyses consider the simultaneous household decision of vehicle and miles traveled, allowing direct comparison with a gasoline tax. Finally, he considers dynamic impacts in the used car market and finds these comprise nearly half the gross welfare cost of CAFE and fall disproportionately on low-income households. Contrary to previous results, the overall welfare costs are regressive.

Kellogg (2017) shows that the implications of gasoline price volatility for the design of fuel economy policies has a strong parallel to Weitzman's (1974) classic model of using price or quantity controls to regulate an externality. Changes in fuel prices act as shocks to the marginal cost of complying with the standard. Assuming constant marginal damages from fuel consumption, an application of Weitzman (1974) implies that a fixed fuel economy standard reduces expected welfare relative to a "price" policy such as a feebate or, equivalently, a fuel economy standard that is indexed to the price of gasoline. When the regulator is constrained to use a fixed standard, he shows that the usual approach to setting the standard—equate expected marginal compliance cost to marginal damage—is likely to be sub-optimal because the standard may not bind if the realized gasoline price is sufficiently high. Instead, the optimal fixed standard will be relatively relaxed and may be non-binding even at the expected gasoline price. Finally, he shows that although an attribute-based standard allows vehicle choices to flexibly respond to gasoline price shocks, the resulting distortions imply that the optimal fuel economy standard is not attribute-based.

3.6. Vehicle markets and policy in China

Another strand of literature we review is that on vehicle markets and policy in China. Huo et al. (2007) develop a methodology to project growth trends of the motor vehicle population and associated oil demand and carbon dioxide emissions in China through 2050. In particular, the numbers of highway vehicles, motorcycles, and rural vehicles are projected under three scenarios of vehicle growth by following different patterns of motor vehicle growth in Europe and Asia.

Projections show that by 2030 China could have more highway vehicles than the United States has today.

China's vehicle population is widely forecasted to grow 6-11% per year into the foreseeable future. Barring aggressive policy intervention or a collapse of the Chinese economy, Wang, Teter and Sperling (2011) suggest that those forecasts are conservative. They analyze the historical vehicle growth patterns of seven of the largest vehicle producing countries at comparable times in their motorization history. They estimate vehicle growth rates for this analogous group of countries to have 13-17% per year- roughly twice the rate forecasted for China by others. Applying these higher growth rates to China results in the total vehicle fleet reaching considerably higher volumes than forecasted by others, implying far higher global oil use and carbon emissions than projected by the International Energy Agency and others.

Lin and Zeng (2013) estimate the price and income elasticities of demand for gasoline in China. Their estimates of the intermediate-run price elasticity of gasoline demand range between -0.497 and -0.196, and their estimates of the intermediate-run income elasticity of gasoline demand range between 1.01 and 1.05. They also extend previous studies to estimate the vehicle miles traveled (VMT) elasticity and obtain a range from -0.882 to -0.579.

Lin and Zeng (2014) calculate the optimal gasoline tax for China using a model developed by Parry and Small. They calculate the optimal adjusted Pigovian tax in China to be $1.58 /gallon which is 2.65 times more than the current level. Of the externalities incorporated in this Pigovian tax, the congestion costs are taxed the most heavily, at $0.82/gallon, followed by local air pollution, accident externalities, and finally global climate change.

Hu, Xiao and Zhou (2014) apply a non-nested hypothesis test methodology to data on Chinese passenger vehicles to identify whether price collusion exists within corporate groups or across groups. Their empirical results support the assumption of Bertrand Nash competition in the Chinese passenger-vehicle industry. No evidence for within or cross-group price collusion is found. In addition, the policy experiments show that indigenous brands will gain market shares and profits if within group companies merge.

Xiao and Ju (2014) explore the effects of consumption-tax and fuel-tax adjustments in the Chinese automobile industry. Applying the model and simulation method of Berry, Levinson and Pakes (1995), they conduct a comparative static analysis of equilibrium prices and sales, fuel consumption, and social welfare before and after tax adjustments. For the first time, they compare the progressivity of both taxes. Their empirical findings suggest that the fuel tax is effective in decreasing fuel consumption at the expense of social welfare, while the consumption tax does not significantly affect either fuel consumption or social welfare.

Li, Xiao and Liu (2015) document the evolution of price and investigate the sources of price decline, paying attention to both market structure and cost factors. They estimate a market equilibrium model with differentiated multiproduct oligopoly using market-level sales data in China together with information from household surveys. Their counterfactual simulations show that (quality-adjusted) vehicle prices have dropped by 33% from 2004 to 2009. The decrease in markup from intensified competition accounts for about one third of this change and the rest comes from cost reductions through learning by doing and other channels.

Liu and Lin Lawell (2017) examine the effects of public transportation and the built environment on the number of civilian vehicles in China. They use a 2-step GMM instrumental variables model and apply it to city-level panel data over the period 2001 to 2011. The results show that increasing the road area increases the number of civilian vehicles. In contrast, increasing the public transit passenger load decreases the number of civilian vehicles. However, the effects vary by city population. For larger cities, increases in the number of public buses increase the number of civilian vehicles, but increases in the number of taxis and in road area decrease the number of civilian vehicles. They also find that land use diversity increases the number of civilian vehicles, especially in the higher income cities and in the extremely big cities. Finally, they find no significant relationship between civilian vehicles and per capita disposable income except in mega cities.

Both market-based and non-market based mechanisms are being implemented in China's major cities to distribute limited vehicle licenses as a measure to combat worsening traffic congestion and air pollution. While Beijing employs non-transferable lotteries, Shanghai uses an auction system. Li (2016) empirically quantifies the welfare consequences of the two mechanisms by taking into account both allocation efficiency and automobile externalities post-allocation. His analysis shows that different allocation mechanisms lead to dramatic differences in social welfare. Although the lottery system in Beijing has a large advantage in reducing externalities from automobile use than a uniform price auction, the advantage is offset by the significant welfare loss from misallocation. The lottery system forewent nearly 36 billion RMB (or $6 billion) in social welfare in Beijing in 2012 alone. A uniform-price auction would have generated 21.6 billion RMB to Beijing municipal government, more than covering all the subsidies to the local public transit system.

4. Data

We have collected a comprehensive annual data set of all the car models marketed from the year 2004 to year 2013 in the Chinese automobile industry. Within each model, we have collected information of price and quantity sales of each displacement of that model. Furthermore, for each model displacement, we also gathered information on vehicles characteristics for each style within that model.

The quantity sales data from year 2004 to year 2013 of each model displacement was collected from the *China Auto Market Almanac*, which includes the quantity sales of all vehicles sold by car manufactures in China, both indigenous firms and joint ventures. We have collected two sets of price data, both in units of 10,000 RMB. The first price variable was collected from *China Automotive Industry Year book* for each model displacement. The other price variable was grabbed from *www.autohome.com.cn*, which is one of the largest vehicle websites in China. (Other famous and widely used car websites are: *http://auto.sohu.com*, *http://auto.163.com*, *http://auto.sina.com.cn*, *http://auto.qq.com*). The price is listed as nominal manufacturer's suggested retail price (MSRP).

We obtain information about vehicle characteristics from *www.autohome.com.cn.* For each style of a certain vehicle model displacement, its characteristics could be divided into the following ten categories. (1) Basic information: the year when such vehicle was produced, dummy for vehicle manufacturers, dummy for vehicle type such as sedan, SUV, MPV, pick-up, sports car, etc. (2) Information about vehicle engines: cylinder layout types; number of cylinders, etc. (3) Information about powertrain: top speed (km/h); acceleration from 0 to 100km/h (in seconds); horsepower (PS); dummy variable for transmission types; number of transmission speeds; types of drivetrain: front engine front drive/ middle engine four-wheel drive, etc.; types of four wheel drive: full time/ real time/ part time; types of power steering: mechanical power steering/ electric power steering etc.; (4) Information about fuel: dummy variable for which type of fuel the vehicle is powered on; fuel efficiency (100km/L), which is the reciprocal of energy intensity (L/100km); displacement (in ml and L); ways of air intake: naturally aspirated, mechanical supercharging; turbo boost, etc.; (5)

Dimensions: length, width, height, wheelbase, all in unit mm; number of doors, passenger capacity (number of seats); (6) Safety equipment: this includes a series of dummy variables for whether the vehicle has been equipped or not: frontal driver air bag; side airbag; brake ABS; front radar; rear radar; back up camera; remote control key; keyless active feature; keyless entry feature; (7) Exterior features: dummy variables for whether the vehicle is equipped with electronic sunroof; panorama sunroof. (8) Interior features: dummy variables for the following features: heated front seats; heated rear seats, ventilated front seats; ventilated rear seats; GPS; bluetooth interface; build-in TV; Air conditioner. (9) Advanced technologies: dummy variables for advanced technologies such as park assist; side assist. (10) For alternative fuel vehicles of which electricity is one of the power sources, there is also information about the electric engine: total power of electric engine (kW); the torque of the electric engine (Newton-metre); energy density (kWh) and charge-depleting range (km). Table A1 in the Appendix provides detailed information about all vehicle characteristics variables.

One unique feature of the Chinese automobile industry is that some of the car manufacturers are state owned. Among the 64 car makers in our sample, 49 of them are state owned. As long as the name of the car manufacturers are different in *www.autohome.com.cn*, we treated those manufacturers as different makers. Since the majority of car companies in China are operated under shareholding system, there are few car companies that are 100% state owned. However, governments do hold a majority of the stocks of some of the companies. We define a stated owned firm as a car manufacturer for which a majority of stock of its parent company (greater than 50%) is held by governments (either central government or local government), although some of its stock might be held by foreign companies, including those with which the firm forms an international joint venture. Information about the ownership of the car companies are referred from *baike.baidu.com* which is used to track back their parent companies, and from *China Industry Business Performance Data of year 2013* as well.

Regarding alternative fuel vehicles, we have 28 model-displacement-style-year observations in total which are powered by alternative fuel sources. These alternative fuel vehicles include hybrid cars powered on both gasoline and electricity, purely electric cars, plug in hybrid cars, and extended range electric vehicles. Of these, 21 model-displacement-style-years were produced after 2010. In the year 2010, the Chinese government established a project called "Energy Saving Projects", using a fiscal subsidy to encourage energy saving. Some autos with small displacement (less than 1.6L) will receive a subsidy (directly to the car makers) such that the market price is the price after subsidized. We will evaluate the effects of this policy on supply and demand. It is possible that this policy encourages the production of vehicles with small displacement.

Table 1 presents summary statistics of the vehicle characteristics of all the car models marketed from the year 2004 to year 2013 in the Chinese automobile industry.

5. Our Research

For our research in Chen et al. (2017), we are developing and estimating a structural econometric model to estimate demand and cost parameters for all vehicles in China. Our structural econometric model of a mixed oligopolistic differentiated products market allows different consumers to vary in how much they like different car characteristics on the demand side and that allows state-owned automobile companies to have different objectives than private automobile companies on the supply side. We apply our model to the annual data we have collected above on sales, prices, and characteristics of the majority of vehicle makes and models in China, including electric vehicles, hybrid vehicles, and alternative-fueled vehicles, over the period 2004 to 2013. Our model enables us to estimate demand- and cost-side parameters, own- and cross-price elasticities, markups, and variable profits for alternative vehicles.

Our structural econometric model in Chen et al. (2017) improves upon conventional econometric analysis using traditional logit models. A traditional logit model of vehicle demand assumes the independence of irrelevant alternatives, and can therefore generate unrealistic substitution patterns. In a logit model, if you take away a car model from the choice set, then consumers of that car will buy other cars according to their market shares. However, in reality, if you remove, say, a luxury car, the consumers of that luxury car are probably more likely to buy another luxury car than a random consumer would, even if luxury cars have low market share.

In contrast, the random coefficients demand model of vehicle demand we use addresses this problem by allowing for interactions between unobserved consumer characteristics and observed product characteristics, thus allowing different consumers to vary in how much they like different car characteristics.

Our research in in Chen et al. (2017) builds on the work of Berry, Levinsohn and Pakes (1995), who develop a model for empirically analyzing demand and supply in differentiated products markets and then apply these techniques to analyze the equilibrium in the U.S. automobile industry. Their framework enables one to obtain estimates of demand and cost parameters for a class of oligopolistic differentiated products markets. Unlike traditional logit demand models, their random coefficients model allows for interactions between consumer and product characteristics, thus generating reasonable substitution patterns. Estimates from their framework can be obtained using only widely available product-level and aggregate consumer-level data, and they are consistent with a structural model of equilibrium in an oligopolistic industry. They apply their techniques to the U.S. automobile market, and obtain cost and demand parameters for (essentially) all models marketed over a twenty-year period. On the cost side, they estimate cost as a function of product characteristics. On the demand side, they estimate own- and cross-price elasticities as well as elasticities of demand with respect to vehicle attributes (such as weight or fuel efficiency).

Our research in in Chen et al. (2017) innovates upon the Berry et al. (1995) work by developing a model of the Chinese automobile market; by including alternative vehicles so that in addition to cost and demand parameters relating to gasoline-fueled vehicles, cost and demand parameters relating to alternative vehicles can be estimated; and by modeling the behavior of not only private automobile companies but also the state-owned automobile companies in China.

Our structural econometric model in in Chen et al. (2017) has several advantages over a survey approach. First, econometric models are estimated using actual data on actual vehicle purchase decisions, and therefore may be more accurate a depiction of consumer preferences, since these preferences are revealed by the actual decisions they make. In contrast, surveys are based on self-reported responses to questions and may be subject to many errors and biases that cause these responses to be inaccurate representations of the truth.

A second advantage of our econometric approach over a survey approach is that we estimate our econometric models using a comprehensive data set we have collected and constructed on sales, prices, and characteristics of the majority of vehicle makes and models in China, and will therefore base our models and analysis on the vehicle purchase decisions of all vehicle owners in China, not just those of the consumers that are surveyed. Our comprehensive data set not only provides more information, but also is not subject to sample selection issues that would plague a survey of a sample of the population.

A third advantage of our econometric approach over a survey approach is that our econometric model enables us to statistically control for multiple factors that may affect vehicle purchase decisions, including price; vehicle characteristics such as fuel economy, horsepower, and size; and consumer characteristics in a quantitative and rigorous manner.

A fourth advantage of the structural model is that the parameters we are estimating enable us to calculate consumer utility, firm profits, and welfare.

A fifth advantage of our structural econometric approach is that it enables us to estimate standard errors and confidence intervals for our parameters, and therefore to ascertain whether our parameters are statistically significant.

A sixth advantage of our structural econometric approach is that we can use the estimated parameters to simulate demand, supply, and welfare under counterfactual policy scenarios. These counterfactual policy simulations will enable us to analyze the effects of vehicle-related policies in China, including those regarding alternative vehicles.

The parameters we are estimating in Chen et al. (2017) enable us to better understand what factors affect the demand and cost of vehicles in China, and how consumers in China trade off various vehicle characteristics (such as fuel efficiency, whether the vehicle is an electric vehicle, etc.) with each other and with price. We use the model to simulate the demand and cost for new vehicles, and also the effects of various government policies on demand, cost, and welfare.

6. Conclusions

China is experiencing rapid economic growth and, along with it, rapid growth in vehicle ownership. The rapid growth in vehicle ownership and vehicle usage is linked to increasing global warming, emissions, air pollution, and other problems. In this paper, we discuss the Chinese automobile industry and government policy; review the literature on automobile supply, demand, and policy; and describe the characteristics of vehicles in the Chinese automobile industry. We also review our work in Chen et al. (2017), in which we analyze the supply and demand for automobiles in China, and the effects of government policy on the supply and demand for alternative vehicles.

Our research in Chen et al. (2017) is significant for industry, government, society, academia, and NGOs. Our model of the demand and cost in the Chinese automobile market will be significant for industry, particularly car manufacturers interested in better targeting cars, including alternative vehicles, for the Chinese market. Our estimates of the factors that affect demand and supply in the Chinese automobile market is significant for policy-makers interested in developing incentive policies to increase market penetration of alternative vehicles with potential environmental and climate benefits.

Biography of the Authors

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Yuan Chen is a Ph.D. candidate in Transportation Technology and Policy at the University of California at Davis. Yuan has received numerous prestigious awards for her research, including the Best Paper Award at the Transportation Research Forum 2017 Annual Conference, a UC-Davis Graduate Student Travel Award, the 2015 Shell Corporate Affiliate Fellowship, and a fellowship from the China Scholarship Council. She was one of the few doctoral students nationwide selected to attend the prestigious 2016 Berkeley Summer School in Environmental and Energy Economics. She has presented her research at the 2016 U.S. Association for Energy Economics (USAEE) North American Conference, the top national conference in energy economics and policy, for which she was awarded a U.S. Association for Energy Economics (USAEE) Student Registration Fee Scholarship and an ITS-Davis Travel Grant; and at the 7th Annual Interdisciplinary Ph.D. Workshop in Sustainable Development (IPWSD) at Columbia University in April 2017. She has also been selected to present her research at the 2017 Asian Meeting of the Econometric Society and at the 2017 China Meeting of the Econometric Society.

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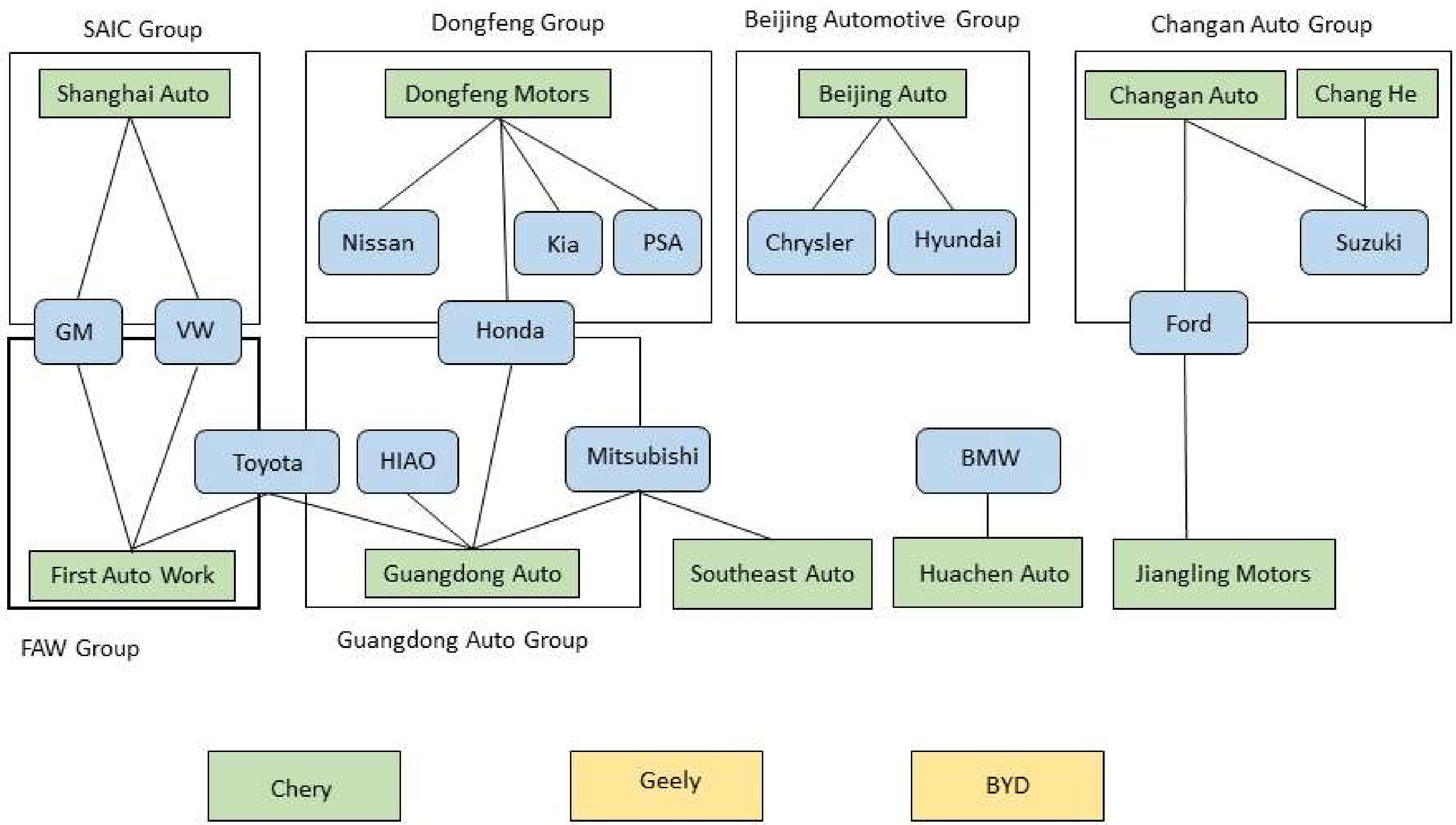
Figure A1: Market Structure of Chinese Automobile Industry



Notes: Chinese firms that are at least partially state-owned are in green. Private Chinese firms are in yellow. Interactional car companies are in blue. Lines connecting firms indicate joint ventures between firms.
Source: Hu, Xiao and Zhou (2014)

Figure 2: Geographical location of Chinese automobile companies

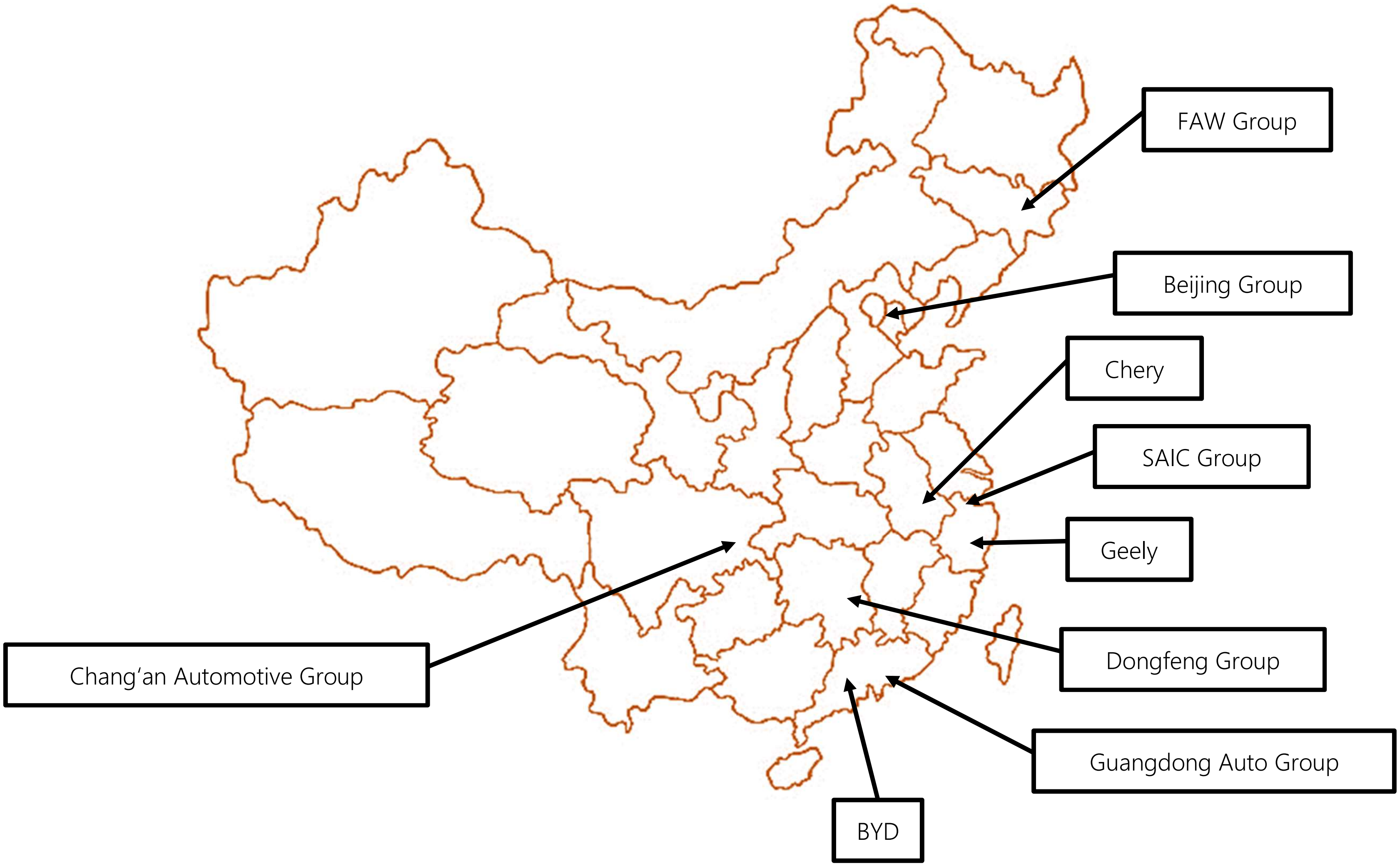


Table 1. Multipliers on alternative fuel vehicles in CAFC calculation

	Type of Alternative Fuel Vehicle			
Year(s)	**pure-electric**	**fuel-cell electric**	**plug-in hybrid**	**energy saving**
~ 2015	5	5	5	3
2016-2017	5	5	5	3.5
2018-2019	3	3	3	2.5
2020	2	2	2	1.5

Note: This table presents the multipliers imposed on the annual sales/imports of alternative fuel vehicles in the CAFC calculation.

Table 2: Variable Description

	Variable	Units	Values
Basic Information	The year of the model style		
	Model-displacement		
	Manufacturer's suggested retail price	10,000 RMB	
	Dummy for Car manufactures		
	Model style		
	Car manufacturer name		
	Category of the model style		1=Mini Car 2=Small Car 3=Compact Car 4=Medium Car 5=Medium-Large Car 6=Large Car 7=Small SUV 8=Compact SUV 9=Medium SUV 10=Medium-Large SUV 11=Large SUV 12=MPV 13=Sports Car 14=Advanced Pickup
	Dummy variable if the model style is import		1=Yes; 0=No

	Body styles		2=2 boxes 3=3 boxes 4=Liftback 5=Wagon 6=Sports Car 7=Sporty car with hard roof 8=Convertible with hardtop 9=Convertible with a folding textile roof 10=SUV 11=MPV 12=Pickup
Price variables	The minimum price of the model style within each model-displacement-year		
	The maximum price of the model style within each model-displacement-year		
Quantity variable			
Engine	Engine type by the manufacturers		
	Cylinder layout types		1=L 2=V 3=W 4=H 5=R
	Number of cylinders		
Electric Engine	Total power of the electric engine	kW	
	The torque of the electric engine	Newton-metre	
	Energy density	kWh	
	Charge-Depleting Range	km	
Powertrain	Maximum volume	km/h	

	Official Acceleration 0-100km/h	second	
	Peak Horsepower	PS	
	Maximum Power	Kw	
	Transmission types		1=MT, 2=AT, 3=DCT, 4=AMT, 5=CVT
	Number of transmission speeds		
	Type of Drivetrain		1=Front engine front drive 2=Front engine rear drive 3=Front engine four-wheel drive 4=Middle engine rear drive 5=Middle engine four-wheel drive 6=Rear engine rear drive 7=Rear engine four drive 8=Double electric four-wheel drive
	Types of the four wheel drive		1=Full time 2=Real time 3=Part time
	Type of Power steering		0=No power steering 1=MPS(Mechanical power steering" 2=HPS 3=EHPS 4=Electric Steer by wire 5=EPS(Electric Power Steering)

Fuel	The type of fuel that this model is powered on		1=Diesel 2=Gasoline 3=Hybrid of gas and electricity 4=Pure electric 5=Plug in hybrid 6=Extended range electric vehicle(E-REV)
	Official energy density	L/100km	
	Official Energy Efficiency	100km/L	
	Displacement	ml	
	Displacement	L	
	Different ways of delivering air into the combustion		1=Naturally aspirated 2=Mechanical supercharging 3=Turbo Boost 4=Mechanical supercharging and Turbo supercharging 5=Twin-turo/biturbo 6=Four-turbo
Dimension	Length	mm	
	Width	mm	
	Height	mm	
	Wheelbase	mm	
	Curb weight	kg	
	Number of doors		
	Passenger Capacity	number of seats	
Safety	Airbag: Frontal-Driver		1=Yes; 0=No; 2=Optional
	Airbag: Side airbag		1=Yes; 0=No; 2=Optional
	Brake ABS		1=Yes; 0=No; 2=Optional
	Parking distance control/Radar-Front		1=Yes; 0=No; 2=Optional

	Parking distance control/Radar-Rear		1=Yes; 0=No; 2=Optional
	Back up camera		1=Yes; 0=No; 2=Optional
	Remote control key		1=Yes; 0=No; 2=Optional
	Keyless active		1=Yes; 0=No; 2=Optional
	Keyless entry		1=Yes; 0=No; 2=Optional
Exterior	Electronic sunroof		1=Yes; 0=No; 2=Optional
	Panorama sunroof		1=Yes; 0=No; 2=Optional
Interior	Heated front seats		1=Yes; 0=No; 2=Optional
	Heated rear seats		1=Yes; 0=No; 2=Optional
	Ventilated front seats		1=Yes; 0=No; 2=Optional
	Ventilated rear seats		1=Yes; 0=No; 2=Optional
	GPS		1=Yes; 0=No; 2=Optional
	Bluetooth interface		1=Yes; 0=No; 2=Optional
	Build in TV		1=Yes; 0=No; 2=Optional
	Air conditioner		Manually=11; Manually(optional)=12; Automatic=21; Automatic(optional)=22; 0=No
New Technology	Park Assist		1=Yes; 0=No; 2=Optional
	Side Assist		1=Yes; 0=No; 2=Optional
Population	The adult population (age 15-64) every year. Source: World Development Indicators.		
Income	Urban income across all provinces every year. (2000,2005,2010, 2011,2012,2013) Source: China Statistical Yearbook		

	The standard deviation of urban income across all provinces every year. (2000,2005,2010, 2011,2012,2013) Source: China Statistical Yearbook		
SOE	Dummy for State Owned Enterprise Information referred from: baike.baidu.com and China Industry Business Performance Data of the year 2013.		1=if governments (central government or local government) holding the majority of the company stocks. (greater than 50%) 0=Privately owned

Table 3: Summary Statistics

Variable	# Obs	Mean	Std. Dev.	Min	Max
Year	6821	2009.727	2.677	2004	2013
Model-displacement	6821	270.393	149.588	1	531
Manufacturer's suggested retail price (MSRP) (10,000 yuan)	6821	14.937	10.946	2.88	89.96
Dummy for car manufactures	6803	32.230	17.452	1	64
Model style					
Category of the model style	6821	4.300	2.844	1	13
Dummy variable if the model style is imported	6821	0	0	0	0
Body styles	6821	4.396	3.122	2	11
Minimum price of model style within each model-displacement-year (10,000 yuan)	3608	11.821	8.051	2.68	53.8
Maximum price of model style within each model-displacement-year (10,000 yuan)	3610	18.361	14.713	3.8	89.95
Engine type by the manufacturers					
Cylinder layout types	6798	1.056	0.231	1	2
Number of cylinders	6794	4.128	0.539	3	8
Total power of the electric engine (Kw)	26	49.096	37.512	12	105
The torque of the electric engine (Newton-meter)	24	196.625	130.227	60	450
Energy density (kwh)	6	19.167	18.809	10	57
Charge-depleting Range (km)	6	136.667	80.416	100	300
Maximum volume (km/h)	5588	182.396	22.857	110	265
Official acceleration 0-100km/h (second)	2598	11.626	2.818	5	35
Peak horsepower (PS)	6802	130.246	38.940	16	350
Maximum power (Kw)	6817	95.754	28.626	12	257
Transmission types	6804	1.717	1.003	0	5
Number of transmission speeds	6815	5.190	1.009	1	9
Type of drivetrain	6805	1.207	0.537	1	3
Types of the four wheel drive	417	2.122	0.751	1	3
Type of power steering	6798	2.838	1.314	0	5
Type of fuel that this model is powered on	6805	1.981	0.175	1	4

Official energy density (L/100km)	6	19.167	18.809	10	57
Official fuel intensity (100km/L)	3928	0.131	0.021	0.075	0.233
Alternative vehicle (dummy)	3928	0.004	0.064	0.000	1.000
Displacement (ml)	6673	1795.832	449.240	970	4700
Displacement (L)	6815	1.808	0.456	1	4.7
Different ways of delivering air into the combustion	6798	1.268	0.679	1	3
Length (mm)	6821	4456.209	359.680	3400	6870
Width (mm)	6821	1755.911	78.352	1495	1997
Height (mm)	6821	1533.149	118.915	1325	1937
Wheelbase (mm)	6815	2630.707	158.776	2296	4950
Curb weight (kg)	5898	1346.930	255.769	815	2940
Number of doors	6807	4.449	0.519	2	5
Passenger capacity in terms of number of seats	6811	5.118	0.506	4	9
Airbag: frontal-driver	6819	0.916	0.306	0	2
Airbag: Side airbag	6820	0.869	0.366	0	2
Brake ABS	6811	0.946	0.239	0	2
Parking distance control/radar-front	6821	0.084	0.288	0	2
Parking distance control/radar-rear	6820	0.627	0.524	0	2
Back up camera	6821	0.174	0.430	0	2
Remote control key	6816	0.886	0.324	0	2
Keyless active	6821	0.163	0.379	0	2
Keyless entry	6821	0.101	0.310	0	2
Electronic sunroof	6821	0.583	0.581	0	2
Panorama sunroof	6821	0.035	0.204	0	2
Heated front seats	6821	0.225	0.476	0	2
Heated rear seats	6821	0.031	0.184	0	2
Ventilated front seats	6821	0.022	0.171	0	2
Ventilated rear seats	6821	0.003	0.066	0	2
GPS	6821	0.279	0.560	0	2
Bluetooth interface	6821	0.234	0.492	0	2
Build in TV	6821	0.031	0.195	0	2
Air conditioner	6821	15.413	5.110	0	21
Park assist	6821	0.014	0.139	0	2

Side assist	6821	0.015	0.146	0	2
Adult population (age 15-64) every year	6821	73.068	0.609	71.065	73.507
Mean of log urban income across all provinces every year (yuan)	4374	4.306	0.102	3.995	4.396
Standard deviation of log urban income across all provinces every year	4374	0.099	0.003	0.096	0.106
Dummy for state-owned enterprise	6821	.678	.4672	0	1