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Policy Improvements of Private Transportation in US and China

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Policy Improvements of Private Transportation in US and China

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Abstract

This dissertation consists of three chapters that investigate policies aiming for improving private automobile transportation from different angles.

The first chapter focuses on the efficiency of marked versus unmarked on-street parking. The study uses computer simulation that assigns queues of randomly generated vehicles to marked and unmarked spaces using a parallel world method, to directly test which method is more efficient and accommodate more cars. The simulation results show that unmarked spacing is more efficient only when the curb is shorter, or not close to any integer times of the optimal length of one marked space, and when drivers are all considerate when choosing the parking location. This simulation study also finds vehicle downsizing only helps the owners of the downsized vehicles themselves, while making it more difficult for all other people to find parking.

The second chapter focuses on the engine size tax in China. Using regressions based on data of vehicle trims offered in China from 2004 to 2016, the study shows that the engine size tax drove automakers to downsize engines and cluster sizes around cutoff points related to the taxes. The tax affects fuel efficiency in opposite directions. On one hand, engine size tax encouraged engine downsizing in China and contribute to an improvement in fuel efficiency. On the other hand, using cutoff points to differentiate tax rates also encouraged automakers to use turbocharging technology to increase horsepower, which compromised improvements in fuel consumption.

The third chapter focuses on the impacts of fuel price changes on vehicle consumption in US and China. This study conducted a comparative analysis of US and China automobile market using historical vehicle sales data linked with gasoline prices and vehicle attributes including fuel consumption rates. The results reveal a major difference in vehicle purchasing behavior between US and China. US consumers are strongly affected by fuel price and purchase vehicles with better fuel economy when gasoline prices are higher and vice versa, while Chinese consumers do not seem to be affected by gasoline price changes much. This difference implies different policies are needed to reduce fuel consumption in the two countries.

Introduction of Dissertation

Since the invention of automobiles, automobiles have facilitated travel on Earth and greatly improved the living quality of human life. They have provided comfort, freedom, and independence for people who own them, and have become one of the most important modes of transportation in many places in the world.

However, the automobile is also a huge burden for our society. There are limited fossil energy resources, but we have used a significant part of it to fuel automobiles. Automobiles have also been a major contributor to air pollution and greenhouse gas emission. They also take up a lot of precious land to store and operate automobiles. With parking space and highways built up to accommodate a lifestyle dependent on private automobiles, cities have also been experiencing problems like sprawl and urban decay. Therefore, efforts need to be made to improve automobile transportation, maximizing its benefits while minimizing its negative impacts.

This dissertation consists of three chapters that investigate policies aiming for improving private automobile transportation from different angles.

The first chapter focus on how curb parking efficiency is affected by parking management methods and vehicle sizes. Parking is a crucial factor in modern transportation. Parking is the final step of any trip made by a private motor vehicle and enables drivers and passengers of private vehicles to have access to their final destination. Ease and availability of parking strongly influences travel choices of drivers. However, if parking is not planned correctly or priced properly, it can also be a huge burden to society. For example, if drivers cannot find parking when they arrive at their destination, they most likely choose to cruise around the block, causing pollution and congestion. In urban centers, cruising contributes 8% to 74% of the total traffic (Shoup 2007). However, increasing parking space and building more parking facilities is not always the best solution, since they will likely impair accessibility for users of other modes of transportation (Manville and Shoup 2005) and encourage more driving.

On-street parking has also been an important topic. Does unmarked on-street parking accommodate more cars—because smaller cars take less space? Or are unmarked spaces less efficient, because of the mismatch effect of very small cars? Should we charge shorter cars less for parking based on their space saving contribution? With so many different factors, deciding on optimal parking policies is not an easy process. To address this uncertainty, this study builds a computerized model to study how randomly generated vehicles are served by a given curb. The study first compares unmarked spacing with marked spacing with a same size-composition of car parking inflow. It then studies whether or not unmarked spacing can be fitted with more cars when a certain portion of cars become smaller.

This chapter uses computer simulation that assign queues of randomly generated vehicles to marked and unmarked spaces, to directly test which method is more efficient and accommodate more cars. The simulation results show that unmarked spacing is more efficient only when the curb is shorter, not close to any integer times of the optimal length of one marked space, and when drivers are all considerate when choosing the parking location. Under other situations, marked spacing accommodates more cars.

This chapter also finds that vehicle downsizing significantly improves parking efficiency when the vehicle is downsized to two-seaters that can vertically park. In other cases, vehicle downsizing only helps the owners of the downsized vehicles, while making it more difficult for other people to find parking. To better benefit from vehicle downsizing, a new type of "block-based" spacing is proposed, which achieves some of the flexibility of unmarked spacing while keeping the mismatch effect relatively low.

Both the second and third chapter investigates factors that may affect the fuel efficiency of the vehicle sold to consumers. Automobiles are usually used for an extensive period of time, and it is generally difficult for people to change driving behavior within a short period (Hughes et al 2008). For this reason, the fuel efficiency of new vehicles has a decisive impact on global oil consumption and carbon emissions. Therefore, it is important to understand how exogenous factors like government policies or gasoline prices affect automobile manufacturer design choices impacting fuel efficiency and carbon emissions.

The second chapter studies whether the engine size tax in China has effectively improved fuel efficiency of the vehicle models offered in China, in addition to other impacts of this policy. Government regulations have greatly impacted the auto market in China. Since the automotive industry is a crucial sector to the national economy, the Chinese government has enforced more regulations than most other countries. The measures the Chinese government have used include implementing and changing the engine size tax, changing the vehicle purchase tax in certain years, subsidizing vehicle sales in rural China, and providing rebates for EVs.[1] Local governments also use license plate and

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[1] 汽车产业调整和振兴规划,(Automobile industry restructuring and revitalization plan), National Assembly of the People's Republic of China, March 20, 2009

registration fees to influence local automobile markets.[2] For a big market that is still emerging, these methods particularly have the potential to make a big difference.

This paper studies a vehicle consumption tax, based on engine size, and its impacts on automakers' decisions. Despite being called a "consumption tax", the tax is actually levied on manufacturers (it will be referred to as an engine size tax in the rest of this paper). The tax base is the manufacture price before retail, but the tax rate differs based on engine size, with vehicles with larger engines subject to a much higher tax rate than vehicles with smaller engines. Despite the importance of the Chinese automobile market under regulation, relatively few papers have investigated it with regard to this consumption tax.

This tax was drastically changed in 2006 and 2008, in the middle of the fastest expansion of the China automobile market. This engine size tax was formulated as a means to improve fuel efficiency as well, but its actual impacts have been debated both within China and abroad. This is due to two reasons: first, when the tax or fee is based upon proxy parameters rather than the actual fuel efficiency rating, it might not effectively improve average fuel efficiency as intended. Second, since tax rates are based on discontinuous cutoff points, manufactures' decisions could be distorted and suboptimal.

Indeed, policies that are based on proxy attributes and cutoff points are not uncommon elsewhere, and similar concerns about these policies exist in other countries. With these concerns in mind, we investigate the impacts of the policy change in China regarding engine size tax on the Chinese automotive industry. Our study aims to understand the following questions for what

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[2] 我国特大城市交通战略的未来走向——京沪城市交通比较与启示（The Future Trend of Transportation Strategy of Mega Cities in China: Insights of Comparison of City Transportation in Beijing and Shanghai）

happens on the supply side:

First, how did the engine size tax impact the attributes of vehicles that automakers supplied to the Chinese market? Did the policy actually drive the automakers to decrease engine size and cluster sizes around the cutoff points?

Second, if the policy did significantly change manufacturing decisions, what is the impact of the change on fuel efficiency? Does it improve or deteriorate the fuel efficiency of vehicles supplied?

Finally, did the policy have similar effects on different manufactures? Do domestic automakers respond to the policy change differently than foreign ones because of different levels of commitment to the Chinese market?

To answer these questions, we used the specifications of all the light vehicles at the trim-level (a trim would be a particular setting of powertrain and accessories for a vehicle model, for example Honda Civic LX) offered on the Chinese market from 2008 to 2016. We used regressions to analyze the impacts of the engine size policy on the supply-side of the Chinese auto market.

This chapter reveals that the engine size tax did drive automakers to downsize engines and cluster engine sizes around the cutoff points of the tax. However, Chinese automakers made the changes earlier than automakers of foreign origins. We also found controversial impacts of the engine size tax on fuel efficiency. On one hand, the engine size tax encouraged engine downsizing in China and contributed to an improvement in fuel efficiency. On the other hand, using cutoff points to differentiate tax rates also encouraged automakers to use turbocharging technology to increase horsepower, which compromised improvements in fuel consumption. For this reason, we recommend a continuous mechanism to regulate engine size tax instead.

The third chapter investigates both US and Chinese automobile market and compares how consumers in these two countries valued fuel efficiency and responded to the fuel price changes differently. The elasticity of vehicle sales with respect to gas price has always been a key issue within the transportation field. In theory, the importance of fuel efficiency of vehicles should be related with consumers' prediction of future fuel price, which directly affects the fuel costs.

As long as vehicle buyers fully incorporated the calculation of future fuel savings when making a purchase decision, and operating externality is correctly adjusted with policy tool like a fuel tax, people should be motivated to prefer more efficient vehicles, other conditions equal. If this is not the case, then intervention for car purchases like a feebate system or CAFE (Corporate Average Fuel Economy) standards are needed.

There is a large body of literature investigating how people value fuel economy when buying new cars (Helfand and Wolverton 2011). There are several reasons we may need more exploration of this problem. First, existing studies reveal tremendous variation in estimates of the value fuel saving. Could it be that this is related with cultural differences across different regions and different demographic groups? While a European study (Grigolon, Reynaert, & Verboven 2014) estimates higher elasticity than a US study (Train & Winston 2007), this may simply be due to the fundamental difference in purchasing behavior of vehicles in Europe and United States. There are also differences between mature and emerging markets, since consumers may lack experience in purchasing cars in new markets. Therefore, comparing vehicle preference changes in relation to gasoline price changes in different countries can be helpful to reveal these differences.

Second, China has been the largest automobile market since 2009. If this trend continues, China will replace United States as the country with the largest automobile fleet and highest greenhouse gas emissions from transportation in the near future. However, there are relatively few studies that investigate how the automobile market in China reacted to changes in fuel prices.

Lastly, the world automobile market also has gone through major changes in the past 10 years. There has been a noticeable increase in the market share of SUVs. In some markets, such as United States, it has even exceeded the share of passenger cars. Previous studies usually focus on different segments of passenger cars but this study contributes to the body of literature by including SUVs in the analysis.

To study these questions, we collected monthly model-by-model vehicle sales data of 2008-2017 both from China and US. We link the data with concurrent gasoline prices and vehicle attributes such as fuel economy, size and power. Then we regress model-level vehicle sales data on gasoline prices and fuel economy to find the impact of fuel price on the relative preference of vehicles with different fuel economy. We also use aggregated data to analyze impact of fuel price on different quartile by fuel economy. There is also a section examining specific vehicle segments in both countries.

The results of these analyses indicate that China and US automobile market have a major difference: while consumers in both countries prefer vehicles with higher fuel economy, fuel price changes don't affect this preference in China as it does in the US. This also means that in China, fuel taxes might not be as effective as in United States to change vehicle purchasing behavior for long term benefits in fossil energy consumption and carbon emission reduction. Instead, other policies like feebates that directly affect purchasing price might be more effective tools to improve long term vehicle composition.

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3. Grigolon, L. Reynaert, M. and Verboven, F.(2014). *Consumer valuation of fuel costs and the effectiveness of tax policy: Evidence from the European car market.* CEPR Discussion Papers No. 10301. Retrieved from http://www.cepr.org/active/publications/discussion_papers/dp.php?dpno=10301
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5. Train, K.E. and Winston, C. (2007). Vehicle Choice Behavior and the Declining Market Share of U.S. Automakers, International Economic Review, vol. 48, no. 4, pp. 1469- 1496. Retrieved from http://eml.berkeley.edu/~train/trainwinston.pdf

Chapter 1: A Simulation Study of the Efficiency of Unmarked On-Street Parking and Vehicle Downsizing

1. Introduction

As many people have realized, parking is a crucial factor in modern transportation. On one hand, parking is the final step of any trip made by a private motor vehicle and enables drivers and passengers of private vehicles to have access to their final destination. Ease and availability of parking strongly influences travel choices of drivers.

On the other hand, if parking is not planned correctly or priced properly, it can also be a huge burden to the whole society. For example, if car drivers cannot find parking when they arrive at their destination, they most likely choose to cruise around the block, causing pollution and congestion. In urban centers, cruising might take 8% to 74% of the total traffic (Shoup 2007). However, increasing parking space and building more parking facilities are not always the wise solutions, since they will likely impair accessibility for users of other modes of transportation (Manville and Shoup 2005), divert from other uses, and encourage more driving. Moreover, new forms of mobility are creating the possibility that demand for parking will diminish. Indeed, the city of Amsterdam announced in April 2019 that it will eliminate 11,000 curb-side parking spaces and replace them with bike paths, green space and sidewalk[3].

To address this dilemma and create a balance of private motorized transportation and alternative transportation, parking can be properly priced, particularly on-street parking which occupies the most precious land in cities (Shoup 1994). Rather than using a market

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[3] A Modest Proposal to Eliminate 11,000 Urban Parking Spots, https://www.citylab.com/transportation/2019/03/amsterdam-cars-parking-spaces-bike-lanes-trees-green-left/586108/

to balance parking demanded with parking supplied, increasing parking space utilization efficiency is an effective solution that meets parking demand without increasing land use of parking. Many efforts have been made to design a better spacing method, with the help of examples such as LED lights and intelligent guidance system.

Researchers have also used computerized simulation to help improve the design of parking lots. Harris and Dessouky (1997) built a simulation model to analyze parking availability at parking lots in Miami university. Vo, Waerden and Wets (2016) also developed a multi-agent simulation tool to help understand car drivers' movements and their effects on parking.

On-street parking has also been an important topic. Shoup (2014) suggested that compared to marked spacing, unmarked spacing can be fitted with more cars, since marked spaces are designed to fit the longest cars. With the same length of the curb, having unmarked spaces makes it possible to fit more small cars. He also suggested a discount for smaller cars since they occupy significant less space for parking.

However, the mechanism of on-street parking might not be that straightforward. Even though smaller cars occupy less parking space, they do not necessarily save space in unmarked spaces. A space previously occupied by a small car might be too short for the next big car to fit in, as Figure 1 shows. In this case, marked spacing can actually better manage the space, as shown in Figure 2. On the other hand, even though a small car can fit in a space previously occupied by a big car, in most cases after this small car has taken the space, the rest of the curb length cannot be used by any other car, unless the small car is really short and less than half as long as the big car. In other words, the small car still takes the whole space left by the big car. This "mismatch effect" offsets the "space-saving effect”, making the comparative efficiency of unmarked spacing and vehicle downsizing unclear.

Figure 1.1: “Mismatch effect” of small cars parking at unmarked curbs

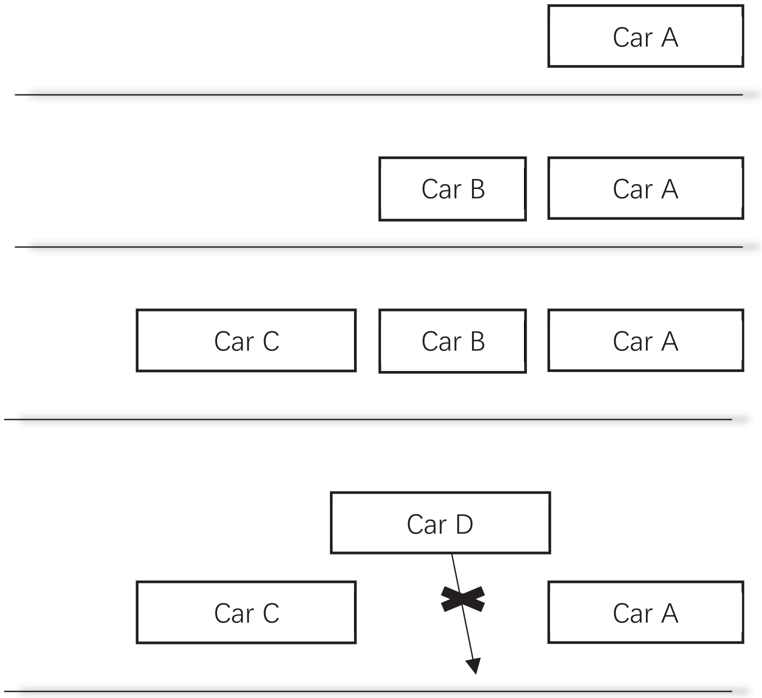
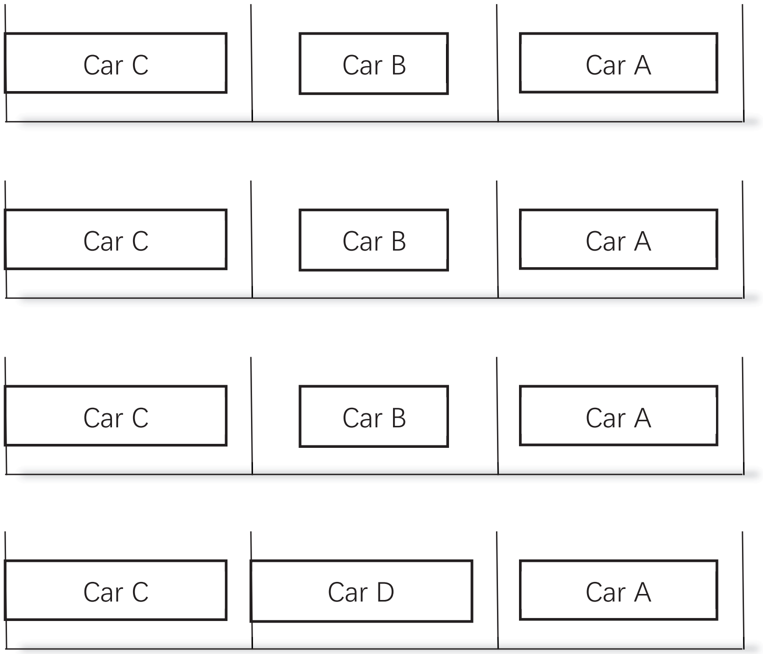


Figure 1.2: Same vehicles handled by marked spacing



To address this uncertainty, this study builds a computerized model to study how randomly generated vehicles are served by a given curb. The study first compares unmarked spacing with marked spacing with the exactly same size-composition of car parking inflow. It then studies whether or not unmarked spacing can be fitted with more cars when certain portion of cars become smaller.

2. Related Works

Even though few previous studies compare the efficiency of the two different ways of managing on-street parking, many have used computer simulation to study parking and its impacts on traffic.

Saltzman developed an animated simulation model called FSTOP to estimate key parking performance measures including the probability of finding a parking space, the time spent searching for a parking space, and the total amount of money put into parking meters (Saltzman 1997). The author found that enforcing a one-hour limit on on-street parking effectively increases turnover and system performance. He also found that replacing current meters with resetting meters, which reset any time left after a car pulls out of a space to zero, increased parking meter revenues by 23%.

Portilla et al.(2009)) used M/M/∞ queueing model to quantify the influence of badly parked vehicles (vehicles that occupy part of the no-parking lane) and on-street parking maneuvers for average link journey times. In this model, the arrivals and departures follow a Poisson’s distribution. It is used to approximate the M/M/C model (Baykal-Gursoy and Duan 2006), with a sufficiently large number of servers. The study found that the travel time for the rest of the link users increase 57 and 107% for vehicles badly parked for 15 and 30 min, respectively, and average journey time for the rest of the users increase by 15, 24, and 39%, respectively, for 10, 20, and 30 minutes maneuvers.

Malecki (2018)) built a computer simulation model using cellular automata and a multi-agent system to study the impacts of different parking behaviors such as patience, perceptivity and use of indicators, on traffic flow. The study found that drivers' parking behavior have a significant impact on traffic flow.

Purnawan (2005) developed a microscopic simulation model to investigate traffic performances adjacent to on-street parking areas during parking operations. The author conducted site surveys using video camcorder for model development, model calibration and validation. The model was developed mainly based on car-following rules, gap acceptance rules and parking and imparking behavior. The model was used to study effects of four different schemes, including parking stall geometric designs, different parking durations, different parking maneuvers with different parking durations, and development of parking prohibition criteria. Both marked and unmarked parallel parking layouts were studied.

These studies all contribute to how simulation models could be developed to study parking. However, they focus on impacts of parking on traffic congestion, or how different parking environment affect maneuver or searching time. This study instead focuses on the impacts of parking space size, whether markings can fit vehicles of different size, and how vehicle downsizing improve parking efficiency in return.

3. Methodology

3.1 Comparison of unmarked spacing and marked spacing

To compare unmarked spacing and marked spacing, the simulation uses a “parallel-world” analysis method where vehicles of different size randomly park. Using different parking layouts (marked or unmarked, different number of parking spaces), vehicles park at different positions of the same curb, resulting in different available spaces afterwards. This difference grows after multiple vehicle parking and departures and depends on whether the next vehicles can be served by the same curb, thus yielding a difference in overall parking success rate.

A queue of vehicles is randomly generated then different two curbs are fed with the same queue of vehicles, one marked and one unmarked. However, since the spacing methods are different, the location where vehicles park are different in these two scenarios. The simulation model then compares how many of them can actually be served with marked spacing and unmarked spacing respectively.

In the model, as every minute passes, there is a fixed chance that a new vehicle is generated to be served by the curb. This chance determines how many vehicles are likely to be generated within a given period. When a vehicle is generated, a parking time is randomly designated to the vehicle. When this parking time is used up, the vehicle will leave and the space is available again. For unmarked spacing, this space will be combined with the spaces ahead and behind it.

There have been studies about how much space a vehicle needs for curb parking. Based on mathematical analysis, Blackburn and Simon (2009) indicated that the real length is related with turning radius, wheelbase, the distance between the front bumper and the front wheel and the width of the vehicle this vehicle is parking behind. However, I use a simplified method to calculate the curb length needed by a vehicle: the length needed by a vehicle is assumed to be the diagonal length of the vehicle, calculated by the length and width of the model.

In the simulation model, the odds of different vehicle size segments are based on their shares among all registered light-duty vehicles. Since more recent data cannot be accessed, a dataset in 2004 is used[4]. The chance of a segment being generated as the next vehicle to be served by the curb space is exactly the same with its share in the whole national fleet. Since this is an exploratory study to find out how different parking spacing methods compare with different efficiencies and real-world vehicle sizes, we still observe a trend even though the actual size composition has changed a bit since 2004. For example, 19.3% of all the light-duty vehicles registered in the United States in 2004 are midsize cars. Therefore. in the simulation, when a new vehicle is generated to be parked, there is a 0.193 chance that this car is a midsize car.

To simplify the procedure to construct this representative fleet, for each automobile class, a vehicle's length and width is used to represent the whole class. The best-selling vehicle model in 2015 for each segment is used as the representative vehicle[5]. For example, the midsize car segment is represented by Toyota Camry. The length of all midsize cars is therefore set to 4850mm and the width of all midsize cars are set to

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[4] "*Passenger Vehicle Occupant Fatality Rates by Type and Size of Vehicle*", NHTSA's National Center for Statistics and Analysis, Traffic safety facts. Research note

[5] "2015 Year End U.S. Vehicle Sales Rankings - Top 288 Best-Selling Vehicles In America - Every Vehicle Ranked", retreived from http://www.goodcarbadcar.net/2016/01/usa-vehicle-sales-by-model-2015-calendar-year-december.html on 06/01/2016

1820mm. The following table shows the share of different vehicle segments and their dimensions:

Table 1.1 Share of different light-duty vehicle segments based on sizes and the dimensions of the representative models

Size Segment	Best-selling model of segment in 2015	Registered number in 2004	Share	Length (mm)	Width (mm)	Diagonal length (mm)
Subcompact car	Kia Soul[6]	21,851,909	9.9%	4140	1800	4514
Compact car	Toyota Corolla[7]	38,318,494	17.3%	4639	1775	4967
Midsize car	Toyota Camry[8]	42,654,513	19.3%	4850	1820	5180
Full-size car	Chevrolet Impala[9]	29,642,017	13.4%	5110	1900	5452
Minivan	Toyota Sienna[10]	13,856,151	6.3%	5085	1986	5459
Large van	Ford Transit[11]	5,072,354	2.3%	6035	2065	6379
Midsize SUV	Honda CR-V[12]	23,246,926	10.5%	4529	1819	4881
Full-size SUV	Chevrolet Tahoe[13]	7,875,001	3.6%	5179	2045	5568
Compact pick-up truck	Toyota Tacoma[14]	13,426,656	6.1%	5392	1890	5714
Standard pick-up truck	Ford F-Series[15]	25,124,684	11.4%	5890	2029	6230

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[6] The specs are retrieved from http://www.kia.com/us/en/vehicle/soul/2016/features on 06/01/2016

[7] The specs are retrieved from http://www.toyota.com/corolla/features/dimensions/1832/1856/1876/1866 on 06/01/2016

[8] The specs are retrieved from http://www.toyota.com/camry/features/dimensions/2532/2540/2546/2548 on 06/01/2016

[9] The specs are retrieved from http://www.chevrolet.com/impala-full-size-cars/specs/trims.html on 06/01/2016

[10] The specs are retrieved from http://www.toyota.com/sienna/features/dimensions/5338/5342/5348/5356 on 06/01/2016

[11] The length and width specs used here are based on the long-wheelbase version of Ford Transit which is the medium-size between regular and long extended. The specs are retrieved from http://www.ford.com/commercial-trucks/transitcommercial/specifications/exterior/ on 06/01/2016

[12] The specs are retrieved from http://automobiles.honda.com/cr-v/specifications.aspx on 06/01/2016

[13] The specs are retrieved from http://www.chevrolet.com/tahoe-full-size-suv/specs/trims.html on 06/01/2016.

[14] The length and wideth specs used here are based on the Toyota Tacoma Access Cab standard bed version. The specs are retrieved from http://www.toyota.com/tacoma/ebrochure/ on 06/01/2016

[15] The length and width specs used here are based on the Ford F-150 Supercab and 6.5 feet cargo box version.

For marked spacing, each marked space should be at least long enough to serve the largest light-duty vehicle. The length of parallel parking required by parking standards in the United States usually requires ranges from 18 to 24 feet (5.5 to 7.3 meters) (Shoup 2011). In rural areas, parking spaces tend to be longer. Bend, a small city in Oregon requires minimum length of 24 feet for an on-street parking space[16]. Vanderburgh County in Indiana has 22-feet parking length standards for parallel parking[17]. Urban areas tend to have shorter on-street parking spaces, for example Oakland city in California assigns only 20 feet length for on-street parking space[18]. In some cases, the length of on-street parking also varies within a county. Arlington county in Virginia near Washington D.C. has 22 feet as the standard for on-street parking space length, but exceptions down to 18 feet are granted on a case by case basis[19]. In this simulation, the length of marked space is set to be 6.38 meter (20.9 feet), which is the length required by the largest vehicle (Ford Transit large van) in the simulated virtual fleet.

For marked on-street parking, the model assumes that every vehicle finds the first empty space to park. For unmarked spacing, the model assumes that every vehicle finds the first space that is long enough to accommodate itself. For any spaces in the middle, this means the space is at least as long as its diagonal length. However, for a space at

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Supercab is the medium-size cab style between Regular Cab and SuperCrew and the 6.5 feet cargo box is also the medium-size cargo box for F-150. The specs are retrieved from http://www.ford.com/trucks/f150/specifications/ on 06/01/2016.

[16] Bend Code, passed October 17, 2018, retrieved Oct 30, 2018 from https://www.codepublishing.com/OR/Bend/html/BendDC03/BendDC0303.html

[17] Vanderburgh County Code, retrieved Oct 30, 2018 from https://www.codepublishing.com/IN/VanderburghCounty/

[18] Oakland Planning Code Codified through Ordinance No. 13501, enacted July 24, 2018. (Supp. No. 48, 9-18). retrieved Oct 30, 2018 from https://library.municode.com/ca/oakland/codes/planning_code?nodeId=16490

[19] Arlington County Infrastructure Standards, H-3.5 On Street Parking. retrieved Oct 30, 2018 from https://topics.arlingtonva.us/wp-content/uploads/sites/21/2013/12/H-3.5-On-Street-Parking.pdf

either the start or the end of the curb, it only needs to be longer than its length, not diagonal length, since the vehicle can always use extra space to maneuver.

The model also needs to determine how vehicles use parking spaces for unmarked on-street parking. This model assume that drivers are in general considerate. If the vehicle is parked at the end of the curb in the moving direction, the model assumes the vehicle will move the vehicle’s front bumper to the very end of the curb. Otherwise, the vehicle moves to the end of the target space, keeping a distance from the vehicle in front just long enough to move out (the distance is equal to the difference of the vehicle’s diagonal length and its length), even if the space is at the start of the curb. If the available space is at the start of the curb, drivers are assumed to forward-park into the space. In this case, they are not likely to reverse the car back to the very start of the curb. Instead, it is much easier to move closer to the car in front of their own car. However, if the space available at the start of the curb is shorter than its diagonal length (which is only possible for spaces at start or end of the curb), the model assumes the car stays right in the middle of the space.

The model simulates the operation of a curb for parking from 8AM to 8PM in a day. The simulation starts with a 31.9-meter-long curb, which can just accommodate 5 marked spaces. That is 3600 space-minutes in 12 hours. The parking time follows normal distribution with a maximum of 120 minutes and a minimum of 15 minutes[20]. Since a vehicle on average park here for 67.5 minutes, the 5-space curb can serve 53 vehicles if the vehicles are continuously arriving.

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[20] The duration of parking time does not actually affect which methods of parking layout is more efficient. It only affects the intervals between vehicle departures. Here the randomly generated parking durations are just used to generate random vehicle departure order.

The default odds of new vehicle generation in every minute is set to be 0.015 for every curb space, which means 54 vehicles are generated to be served over 12 hours. This indicates the parking supply and demand are almost balanced. However, when a car leaves, the next car may not have arrived yet, generating some waste of available parking resources. The proportion of generated vehicles that get served are compared across the two different types of parking layouts.

This study includes four additional scenario analyses. The first changes the curb length from 5 marked spaces to a number of spaces equal to an integer times of marked space length to see whether or not the trend changes. The second changes the new car generation rate to see how the unmarked spacing's comparative efficiency changes with different demand-to-supply ratio. The third one changes the curb length. If the curb length is not an integer length of one marked space, the marked spacing will have a disadvantage because part of the curb will be wasted, while this is not the case with unmarked spacing.

The last scenario analysis changes the parking behaviors of drivers. One is even more considerate, with the driver always backing up his/her vehicle to the very start of the curb when the available space is at the start. The other is less considerate, with the driver always staying in the middle of the available space, sometimes leaving two "half-spaces" in front and behind his/her vehicle. This is only a theoretical test of different parking behaviors. In future studies, researchers could use empirical behavior distribution information collected from the real world.

One drawback of this study is that it does not investigate the effects of parking space size on necessary time to complete a parking maneuver and its impacts on traffic congestion. Further research could build a more detailed model involving both the macro effects of parking space (what vehicles could be fit) and micro effects of parking space (how it affects each parking procedure).

3.2 Effects of vehicle downsizing and block-based parking

In the second part of this paper, I study the effect of vehicle-downsizing with unmarked spacing by using a different vehicle size composition. 80% of the generated vehicles are assumed to be the same size as before, while 20% of them are “additional vehicles”, which are either very big vehicles (large vans like Ford Transit) or very small vehicles (subcompact cars like Kia Soul). Again, the model uses a “parallel-world” method. The two curbs with unmarked spacing are fed with exactly the same randomly generated queue, except the “target cars” are different sizes.

What if we make the cars even smaller, with sizes similar to the Smart Fortwo? While city cars are not popular in the United States, they are much more common in the Europe. Because cars like Smart Fortwo are so short, they can be vertically parked where other cars are parallel parked.

Unmarked spaces can benefit from further downsizing, while marked spaces cannot. To address this issue, I design the block-based parking, dividing a marked space into 3 blocks of equal length, as shown in Figure 1.3[21]. This method is a good balance between the two different types of parking spacing, allowing some flexibility in how much space each car takes, and also reducing the mismatch effect since the way cars are parked still conform to the blocks.

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[21] Each space is divided into 3 blocks

Figure 1.3 Parking Blocks

With this type of parking design, most cars occupy 3 blocks, just like they occupy 1 marked space. However, a Smart Fortwo only takes 1 block with perpendicular parking. City cars like Chevrolet Spark, Fiat 500 and Mini Cooper take 2 blocks, since the length they need to fit in is less than two-thirds of what is needed by the biggest vehicles.

Figure 1.4 A perpendicularly parked Smart Fortwo[22]

In the second part of vehicle downsizing section, I compare the parking efficiency of the three different types of parking spacing: unmarked spacing, marked spacing and

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[22] Retrieved from https://archive.4plebs.org/o/thread/19651600/ , photographer unknown

block-based spacing. For each type, I will simulate 3 scenarios. The first scenario is the same as the first step, making 20% additional cars the Ford Transit. The second scenario is transforms 20% additional cars into Mini Cooper, and the third makes them Smart Fortwo. For the rest 80% of generated cars, I also add a new segment of cars, represented by the Mini Cooper. The odds for the random generation of this segment is based on the sum of market share for Mini Cooper, Fiat 500 and Chevrolet Spark in 2015.

4. Results

4.1 Comparison of unmarked spacing and marked spacing

The simulation model is implemented with a Python program. Because the randomness of the generated vehicle queue actually has strong influence on parking accommodation success rate, each success rate is the average value of 10,000[23] simulations of the same program. The results are shown in the following four tables.

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[23] This study is based on simulation, not field data. However, because each simulation also has randomness, having two few executions might result in a biased result. We could assume that if infinite simulations are executed, the average success rate is the "true mean". Then, if we treat $+\infty$ as the "population size", and require 95% confidence level and 1% confidence interval, the sample size needs to be greater than 9604. Therefore, this study use 10,000 executions to guarantee the result is no worse than 95% confidence level and 1% confidence interval.

Figure 1.5 Comparison of marked/unmarked spacing success rates for different curb lengths (curb length is fixed to 5 marked space)

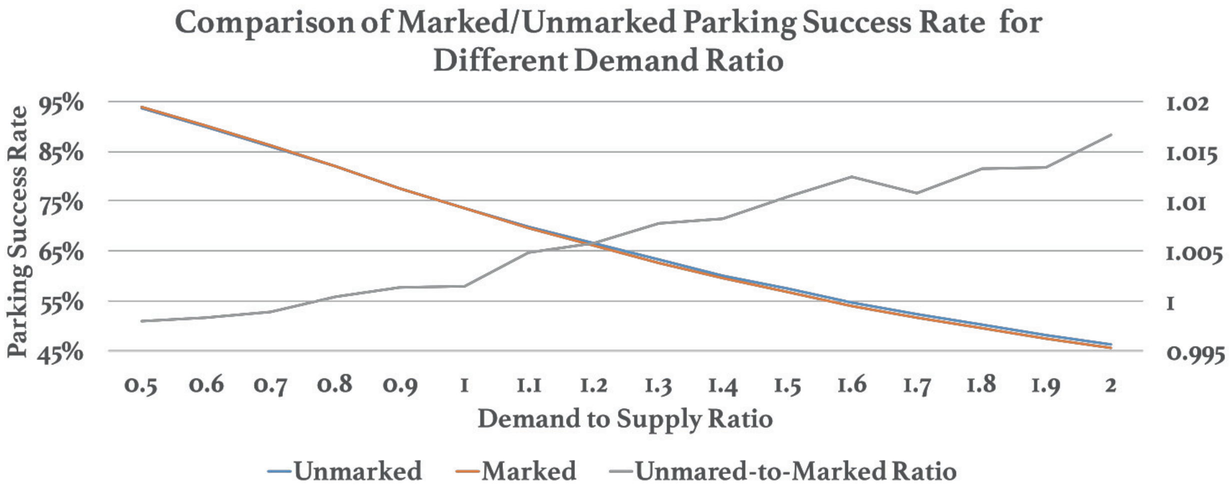


Figure 1.5 reveals as demand-to-supply ratio becomes higher, unmarked spacing's disadvantage decreases. If parking is scarce enough, it actually starts to accommodate more vehicles than marked spacing. This is because when parking is scarce, there is a larger "surplus" of vehicles to be parked. There are more short cars searching for parking, making the "mismatch effect" of smaller cars less significant. If a space left open by a short car is too small for most cars, when parking demand is high, there will always be another short car that can fit in. However, the difference between marked and unmarked parking is not big, with the biggest difference at only 2%, indicating that choosing the better method only results in a small improvement.

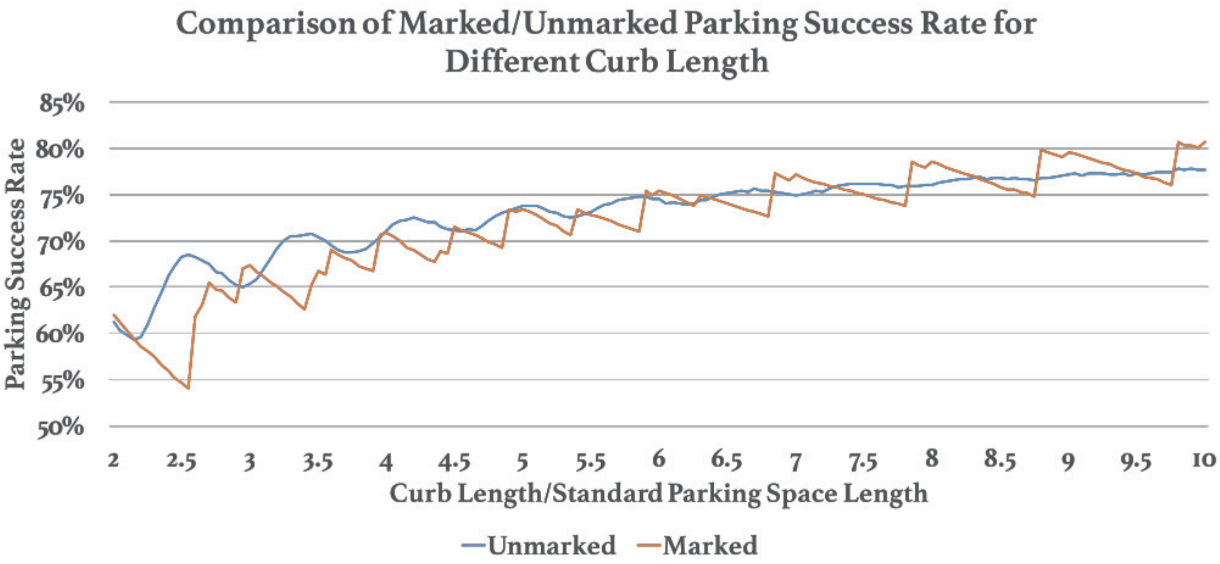
If parking demand is high, marked spacing can be changed to make it more efficient. If some cars are not going to be served anyway, the parking space could be sized to exclude the biggest cars to save space. For example, in this simulated fleet, only 2.3% of the vehicles are as large as the Ford Transit, which needs at least 6.38 meter of curb length to park. If the marked space is set according to the next largest segment, full-size pickup trucks like F-150, the marked space length could be reduced to 6.23 meters. Furthermore, the marked space length could be set from 5.71 meters to 5.57 meters which is still capable of accommodating most cars.

Table 1.2 Efficiency comparison of marked spacing and unmarked spacing with different parking demand level and different marked space length (the best length for each demand level is marked red)

Marked to Unmarked Ratio		Vehicle Generation Rate					
Marked Space Length	Vehicle Coverage	0.01	0.015	0.02	0.025	0.03	0.035
6.38	100.0%	1.0147	1.0076	1.0025	0.9931	0.9870	0.9838
6.23	97.3%	0.9993	1.0137	1.0060	1.0053	1.0030	0.9903
5.71	85.9%	0.9576	1.0185	1.0607	1.0738	1.0945	1.0895
5.57	79.9%	0.9117	0.9738	1.0156	1.0648	1.0745	1.0896

As Table 1.2 shows, when parking demand increases and parking spaces become relatively scarce, the best practice is to make marked spaces a bit smaller, rather than shifting to unmarked spacing. The scarcer parking is, the smaller the optimal marked space is since fewer cars are served.

However, in most cases, planners can only design the optimal parking with the given curb length, rather than set the curb length to the optimal level. For marked spacing, the curb length might not be close to the integer factor of the optimal length of a single space. Figure 1.6 Comparison of marked/unmarked spacing success rate for different curb length (new car generation rate is fixed to 0.015 per minute per space)



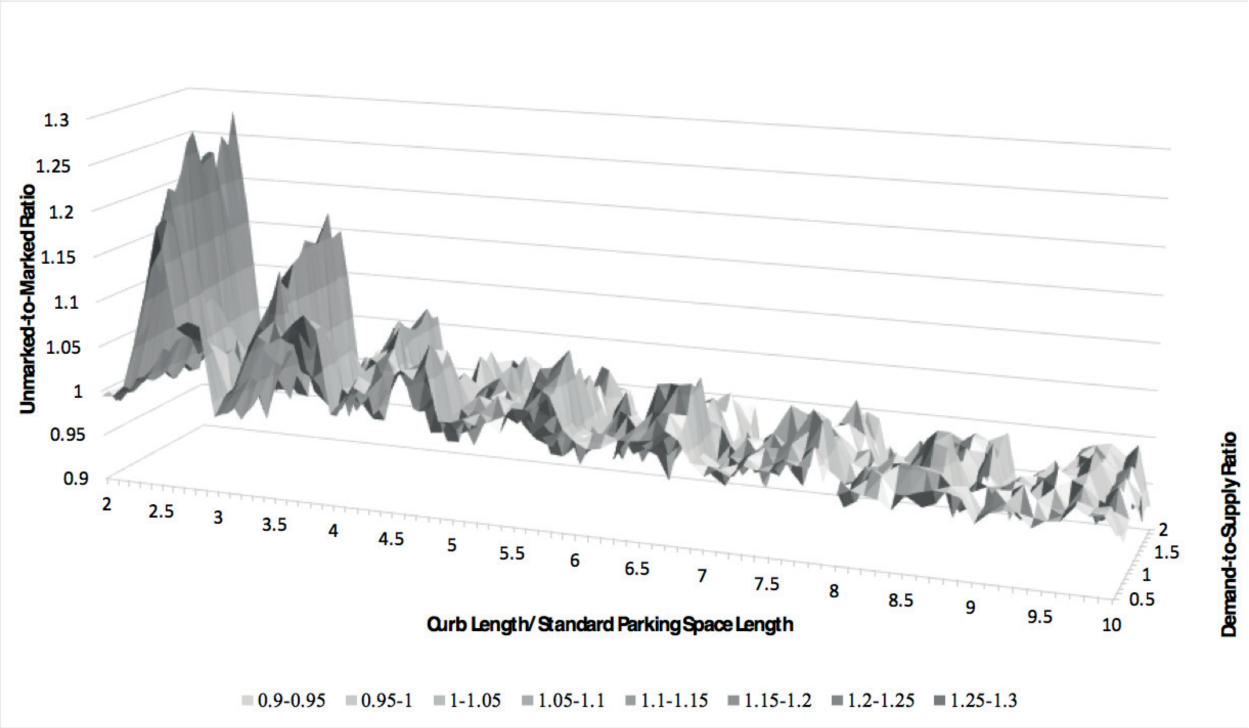
As the simulation results in Figure 1.6 show, if the curb can be divided into an integer factor of a marked space, then it can accommodate more vehicles than unmarked spaces.

When the curb lengths are between an integer factor of the marked spacing space, the efficiency of marked spaces decreases. With unmarked spacing, a curb with a length of 3.5 marked spaces can accommodate either three or four vehicles depending on the vehicle length. On the other hand, if the marked space can only accommodate three cars and the rest of the curb is wasted. The difference reaches 14% in parking success rate, indicating that choosing the superior method has much larger benefits.

However, as curbs increase in length, adding an additional space to marked spaces and making each space a bit smaller might be more efficient. This is particularly true when the reduced marked space length is closer to the optimum for this demand level, which is discussed previously in Table 1.2. In Figure 1.5 this is shown as the red line gets higher relative to the blue line as curb length gets longer.

The comparison between unmarked and marked spacing is further explored by interacting both curb length and demand-to-supply ratio. In this analysis, instead of determining the number of parking spaces using the standard parking spaces, a different number of parking spaces for marked spacing are compared, with the most efficient number chosen to be compared with unmarked spacing. This makes marked spacing more efficient with longer curb lengths and a higher demand-to-supply ratio, as shorter spaces are used when demand is higher. The results are shown in the following contour map:

Figure 1.7 Contour map of unmarked vs. marked spacing efficiency with different curb lengths and demand-to-supply ratio

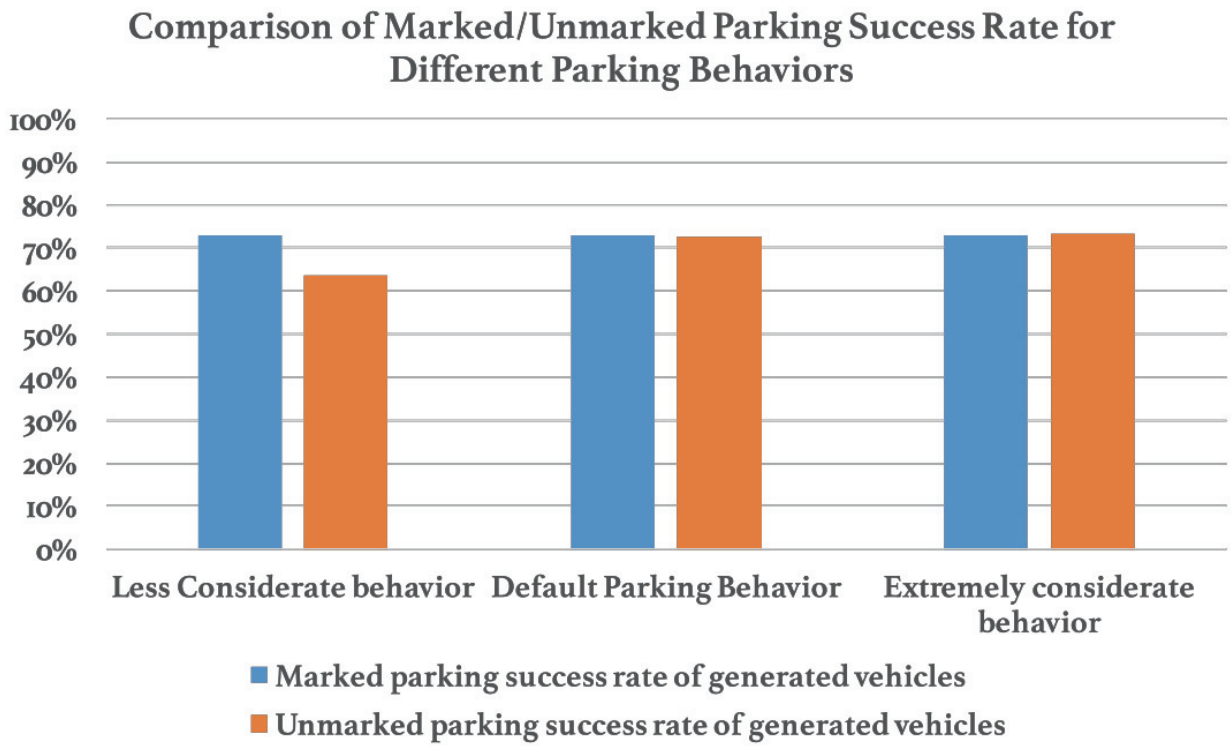


Again, similar to Figure 1.6, one can observe that as curb length increases, the efficiency ratio of unmarked to marked spacing becomes more stable, regardless of whether the curb length is close to the standard parking space length.

Longer curb lengths also make marked spaces more efficient, since the benefits of unmarked spacing's flexibility shrinks, while the "mismatch effect" has a bigger impact as more vehicles parking together. Marked spacing also performs better with higher demand-to-supply ratio. As previously discussed, there is also more flexibility for marked spacing when setting different numbers of spaces and space lengths. It is easier to find a better balance to maximize parking success rate for marked spacing.

Besides parking demand and curb lengths, parking behavior also strongly affects the comparison between the two parking spacing methods.

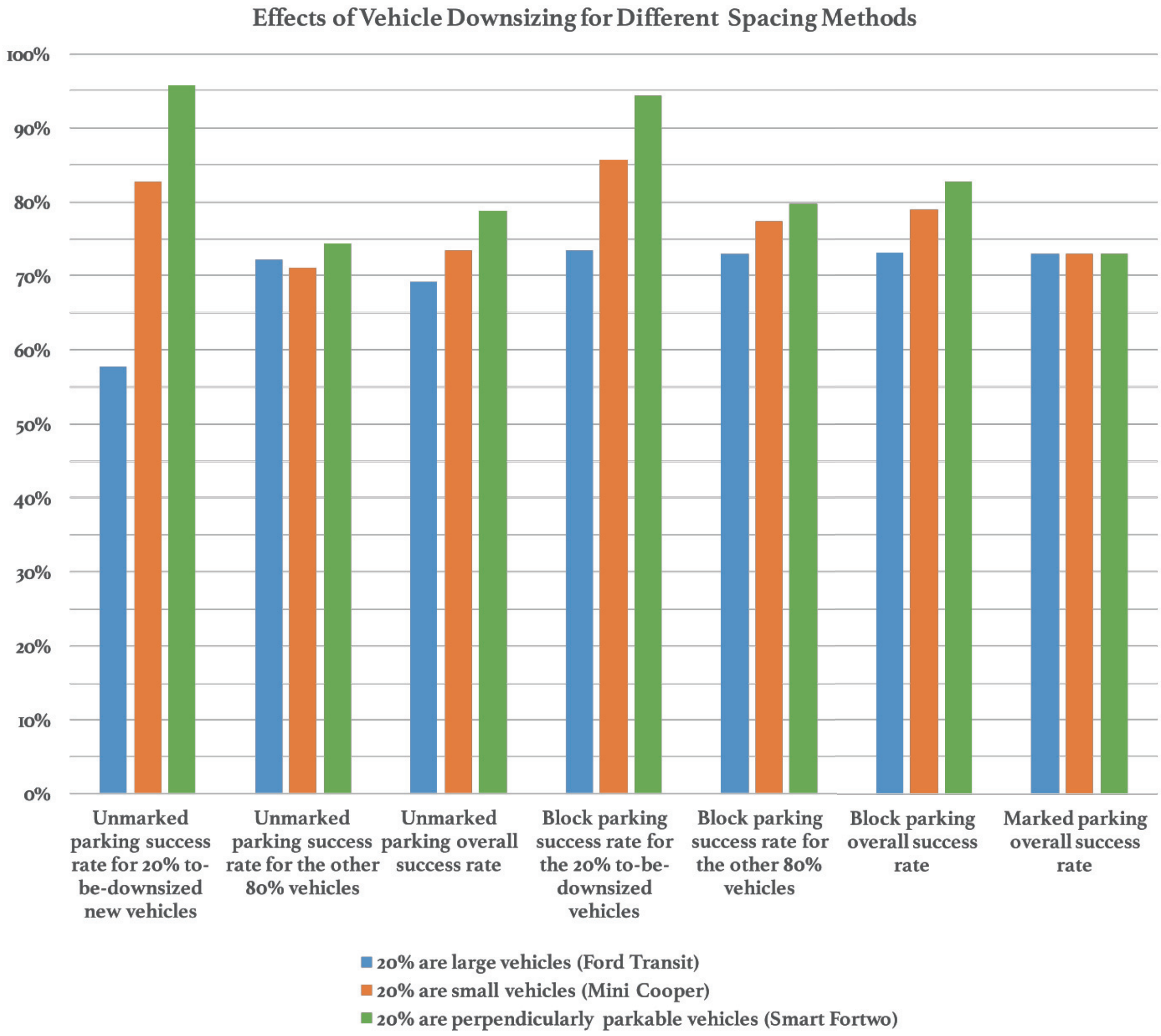
Figure 1.8 Comparison of Marked/Unmarked spacing Success Rates for Different Parking Behaviors



As Figure 1.8 shows, unmarked spacing is significantly less efficient when drivers are not considerate to others. It is more efficient when everyone tries best to make it easier for future vehicles to be parked. However, which behavior actually resemble real-world drivers remains to be studied. And if unmarked spacing is implemented, encouraging drivers to be more accommodating for others will be crucial to its success.

4.2 Effects of vehicle downsizing and block-based parking

Figure 1.9 Effect of downsizing for different spacing methods



As seen in Figure 1.9, downsizing 20% of the fleet from large vans to subcompact cars increases the overall successful parking rate (69.6% to 73.12%). However, all of the benefits are for small vehicles. Because they need much shorter spaces to squeeze in, they have a much higher chance of finding parking space. But because of the “mismatch effect”, these small vehicles actually reduce the chance for other vehicles to find unmarked spacing. In other words, downsizing 20% of the fleet has a negative externality. Even though downsizing these cars increases the overall efficiency of unmarked spacing, it is questionable whether they should be charged less.

Since the curb length is a factor of the length of one marked space, marked spacing is quite efficient. Even when downsizing 20% of the largest vehicles, unmarked spacing only has a slight advantage over marked spacing (73.12% to 73.09%). And for marked spacing, downsizing some of the largest vehicles do not help. To increase efficiency for marked spacing, the government needs to reduce the maximum length and width allowed for light-duty vehicles. If the largest vehicles in the fleet become smaller, the size of one marked space can be smaller, and a given curb might be able to accommodate more marked spaces.

However, cars like the SmartFortwo will better utilize unmarked curbs compared with the other scenarios. Not only is the overall success rate improved (78.74% compared with 69.29% and 73.4%), the remaining 80% of the vehicles also benefit (74.41% compared with 72.22% and 71.02%).

We can also see that for each of the scenario, block-based spacing performs the best. Under block-based spacing, it is easier for small cars to find parking, but it also minimizes the mismatch effects smaller cars cause for others. Under the scenarios of 20% of Smart Fortwo, even though the parking success rate for these cars are slight lower for block-based spacing compared with unmarked spacing, the success rates for the rest 80% vehicles are much higher (79.7% compared with 74.41%).

5. Conclusion

The simulation results of this study indicate that unmarked spacing is not necessarily more efficient than marked spacing. For areas where curbs are very segmented, the utilization rate of marked spacing is very limited and where drivers are very considerate for others when choosing parking locations, unmarked spacing could accommodate more cars than marked spacing. For other areas where curbs are longer or close to a multiple of the ideal length of a parking space, marked spacing actually performs better, due to the absence of the mismatch effect.

With the method provided by this study, city governments could use first-hand data of local fleet composition, parking behaviors, lengths of each curb, and relative parking demand to help decide the best spacing method and length of parking spaces. With the help of the model developed in this study, parking efficiency could be increase as much as 15% simply by choosing the better layout.

For unmarked spacing, despite the intuition that smaller vehicles in general increase the on-street parking accommodation capacity, even extreme downsizing (replace the largest vehicles with subcompact vehicles) only moderately increases parking efficiency. Replacing the largest cars with smaller cars only make parking easier for the car owners themselves. However, this makes it more difficult for the rest of fleet, which have not yet downsized, to find parking. This negative externality makes subsidizing smaller cars for their parking efficiency questionable.

However, downsizing to sizes possible for perpendicular parking like the Smart Fortwo, or block-based parking will make downsizing a more effective strategy. For regions where very small cars can sell a significant amount, cities should consider giving parking rate discounts for those cars, and promote this new method of managing on-street parking. Regardless of whether very small cars are popular, the owners of compact cars would still significantly benefit from ease of locating spots and parking.

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Chapter 2 Engine Size Tax and Chinese Automobile Supply

1. Introduction

For many years, automobiles have been a major contributor to greenhouse gas emissions and fossil energy consumption. Automobiles are usually used for an extensive period of time, and it is generally difficult for people to change driving behavior within a short period (Hughes et al 2008). For this reason, the fuel efficiency of new vehicles is a central driver of global oil consumption and carbon emissions. Therefore, it is important to understand how exogenous factors like government policies affect automobile manufacturer design choices impacting fuel efficiency and carbon emissions.

Among all countries, China is a particularly interesting market to investigate. The Chinese automobile market has been the largest in the world since 2009. Light duty vehicles in China emit more greenhouse gas than those of any other country except for the United States. However, the Chinese automobile market is still considered an emerging market. The annual sales volume is still growing, with 28 million units sold in 2016, more than twice the 13 million sold in 2013. The penetration rate of automobiles is also relatively low. As of the end 2017, China has 157 vehicles per 1000 people, still significantly fewer than any developed country. The Chinese automobile market has been rapidly changing, which means two things: first, it needs to be studied more frequently than other countries; second, it is one of the only major automobile markets that still shows characteristics of an emerging market rather than a mature market. Finally, China might provide a guide to new vehicle adoption as income rises for other developing countries.

Government regulations also greatly impact the auto market in China. Since the automotive industry is a crucial sector to the national economy, the Chinese government has also enforced more regulations than most other countries. The Chinese government has used measures including implementing and changing the engine size tax, changing the vehicle purchase tax in certain years, subsidizing vehicle sales in rural China, and providing rebates for EVs.[24] Local governments also often use license plate and registration fees to interfere with local automobile markets[25]. For a big market that is still emerging, these methods particularly have the potential to make a big difference. However, despite the importance of an analysis of the Chinese automobile market under regulation, relatively few papers have investigated the market.

This paper studies a vehicle consumption tax (its tax rates are based on the engine size) and its impacts on automakers' decisions. Despite being called a "consumption tax", the tax is levied on manufacturers (it will be referred to as an engine size tax in the rest of this paper). The tax base is the manufacturer price before retail, but the tax rate differs based on engine size: vehicles with larger engines are subject to a much higher tax rate than vehicles with smaller engines.

This tax was drastically changed in 2006 and 2008, in the middle of the fastest expansion of the China automobile market. This engine size tax was formulated as a means to improve fuel efficiency as well, but its actual impacts has been debated both within China and abroad. This is due to two reasons: first, when the tax or fee is based upon proxy parameters rather than the actual

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[24] 汽车产业调整和振兴规划,(Automobile industry restructuring and revitalization plan), National Assembly of the People's Republic of China, March 20, 2009

[25] 我国特大城市交通战略的未来走向——京沪城市交通比较与启示（The Future Trend of Transportation Strategy of Mega Cities in China: Insights of Comparison of City Transportation in Beijing and Shanghai）

fuel efficiency rating, it might not effectively improve average fuel efficiency as intended. Second, since tax rates are based on discontinuous cutoff points, manufactures' decisions could be distorted and suboptimal. Policies based on proxy attributes and cutoff points are not uncommon elsewhere, and similar concerns about policies with sharp discontinuity exist in other countries.

With these concerns in mind, I investigate the impacts of the policy change in China regarding engine size tax on the supply side of Chinese automotive industry. This study aims to understand the following questions for what happens on the supply side:

First, how did the engine size tax impact the attributes of vehicles that automakers supplied to the Chinese market? How did automakers comply with the regulations? Did the policy actually drive the automakers to decrease engine size and cluster sizes around the cutoff points?

Second, if the policy did significantly change manufacturing decisions, what is the impact of the change on fuel efficiency? Does it improve or deteriorate the fuel efficiency of vehicles supplied?

Finally, did the policy have similar effects on different manufactures? Do domestic automakers respond to the policy change differently than foreign ones because of different levels of commitment to the Chinese market?

To answer these questions, we used the specifications of all the light vehicles at the trim-level (a trim would be a particular setting of powertrain and accessories for a vehicle model, for example Honda Civic LX) offered on the Chinese market from 2008 to 2016, and used regressions to analyze the impacts of the engine size policy on the supply-side of the Chinese auto market.

The analyses show that the engine size tax did drive automakers to downsize engines and cluster sizes around the cutoff points. I also found two impacts that push in opposite directions of the engine size tax on fuel efficiency. On one hand, engine size tax did encourage engine downsizing in China and contribute to an improvement in fuel efficiency. On the other hand, using cutoff points to differentiate tax rates also encouraged automakers to use turbocharging technology to increase horsepower, which compromised improvements in fuel consumption. For this reason, I recommend a continuous mechanism to regulate engine size tax instead. We also found that Chinese automakers made the changes earlier than automakers of foreign origins.

This paper consists of seven sections. Section 2 reviews the background of the engine tax in China and its controversies. Section 3 presents a model on how engine size tax affect manufacture decisions on engine size. Section 4 describes and summarizes the data used for this study. Section 5 presents results from different sets of regressions studying the impacts of the engines size on vehicles offered in China and estimated the effects of the tax. Section 6 compares the impacts of the engine size tax on different types of manufacturers. Section 7 is conclusion.

2. Background

2.1. Vehicle Related Tax and Fees in China

The engine size tax in China that this study investigates was first implemented in 1994[26]. The tax base is the manufacture price before retail, and the rates were differentiated based on engine displacement. Government stated the tax was established to “adjust product structure and guide

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[26] “Provisional Regulations on Consumption Tax of the People's Republic of China”, China State Council Order No. 135

consumption direction”[27].

The differences in tax rate between different engine sizes was initially small. However, the two changes made to the tax in April, 2006 and August 2008 made the differences much greater. The change in engine size tax rate for different engine sizes are listed in the following table:

Table 2.1: Engine size Tax Changes since January, 1994[28]

Engine Size (Litre)	Tax Rates Before March 2006	Tax Rates April 2006 to August 2008	After September 2008
>4	8%	20%	40%
3-4	8%	15%	25%
2.5-3	8%	12%	12%
2.2-2.5	8%	9%	9%
2-2.2	3%	9%	9%
1.5-2	3%	5%	5%
<=1.5	3%	3%	3%
	3%	3%	1%

There are also other taxes related to engine size in China alongside the vehicle consumption

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[27] “Provisional Regulations on Consumption Tax of the People's Republic of China”, China State Council Order No. 135

[28] Wagner, David Vance, An, Feng, Wang, Cheng. (2009). Structure and impacts of fuel economy standards for passenger cars in China. Energy Policy Volume 37, Issue 10, October 2009, Pages 3803-3811

tax, though those are not the focus of this study. The vehicle purchase tax was introduced in 2001[29]. It replaced the vehicle purchase fee introduced in 1985. When introduced, the tax rate was a uniform 10% of vehicle purchase price applied to all automobiles sold in China. However, the purchase tax rate was cut in half on January 20, 2009 for vehicles with an engine size smaller than 1.6 liters. The tax incentive was set to expire at the end of 2009. However, the tax incentive was later announced to be extended for another year. The tax rate was raised to 7.5%, still lower than 10%, for vehicles with engines smaller than 1.6 liters. The rate then was raised back to 10% on January 1, 2011. A similar extension happened again on October 1, 2015, this time lasting until the end of 2016. For the year 2017 it was lowered again to 7.5%, and was scheduled to return to 10% in early 2018[30].

The vehicle registration tax, which is collected by local governments in China, is also often related with engine size. For example in Beijing[31], vehicles with engines smaller than 1 litre only pay CNY￥300 (US$43.65) for vehicle registration tax annually, while vehicles with engines bigger than 4 litre pay CNY￥4400 (US$640.2).

Despite the existence of multiple taxes related to engine size, this study focuses on the engine size tax since it is long-term and is applied uniformly to the entire country.

2.2. Controversies with Similar Types of Taxes

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[29] "中华人民共和国车辆购置税暂行条例(People 's Republic of China Vehicle Acquisition Tax Provisional Regulations", State Administration of Taxation, August 19, 2005.

[30] "关于减征 1.6 升及以下排量乘用车车辆购置税的通知(Notice on Reduction of Purchase Tax on Passenger Car Vehicles with Displacement of 1.6L and Below)", State Administration of Taxation, December 13, 2016.

[31] "北京市实施《中华人民共和国车船税法》办法",Measures for the Implementation of the Law of the People's Republic of China on Vehicle and Vessel Tax

Because of the way the tax is collected, the engines size tax in China is controversial in many ways. This section cites international practices and academic discussion to provide reader a sense of the controversies.

The first controversy is that the engine size tax is based on engine size, which is an imperfect proxy of what we actually care about: fuel consumption rate.

This engine size tax in China is a tax based on a vehicle attribute. This type of tax differentiates tax/fee rates based on the values of certain attributes of the car that could be directly measured as is, such as engine size, weight, vehicle body size, and horsepower, instead of performance ratings like fuel efficiency ratings or emission ratings that were based on the entire vehicle tested as a whole.

The tax could be assessed in different forms. It could be imposed before the sales price, a sales tax or purchase tax or license plate fee that consumers pay on top of the sale price of the vehicle, or an annual circulation tax, road tax, or license renewal fee that owners of the vehicles pay repeatedly every year. No matter what form the tax is collected and calculated, the major reason for collecting tax based on vehicle attributes is that these attributes could act as proxies for one or many vehicle characteristics and are easier to measure.

In the case of the Chinese engine size tax (also known as a vehicle consumption tax), when the tax was introduced in 1990s, engine size was considered to be a good proxy for many other important attributes (Verboven 2002). Vehicles with bigger engines are usually larger in size, take up more road space and parking space, are heavier and cause more damage to the road, emit more greenhouse gas and air pollution, consume more fossil energy, are more expensive, and sometimes considered to be luxury goods.

Compared to vehicle performance ratings like fuel economy and emission per kilometer, which directly measure the fuel consumption rate or emission rate per kilometer of driving, engine size is easier to measure and much less susceptible to cheating or manipulations targeting the regulation (Fullerton and Sarah 2002).

Many other countries have also previously used similar tax policies that use vehicle attributes as proxies for vehicle fuel consumption and emissions, instead of having taxes on official fuel efficiency rating or carbon emission rating. For example, France has used a tax based on “fiscal horsepower” since World War II, to promote vehicles that are affordable for the general public. Despite the “horsepower” in the name, the tax is actually assessed based on the cylinder bore. The formula was later changed in 1956 to incorporate the number of cylinders and cylinder bore as well, which basically translates to the size of the engine (Fergusson and Taylor 1996). Germany, United Kingdom, Belgium and many other European countries also used this type of taxation in the 20th century. The reason these taxes and fees were designed in such ways are complicated, but it usually involves the intent to promote sales of more efficient vehicles (European Commission 1997).

However, since the late 1990s most European countries have shifted to a taxation method directly based on the emissions (European Commission 2002), while China has continued to use an attribute-based method. Even though the Chinese Average Fuel Consumption (CAFC), which is modeled after the Corporate Average Fuel Economy of United States, was introduced in 2004, the vehicle consumption tax was levied by the Chinese government as one of the most important policy tools to keep the market shares of less efficient vehicles at bay (Olivera et al 2009).

As internal combustion engine technology progressed significantly in recent years, people have argued that engine size no longer correlates well to those attributes as it once did (Ferguson 2016). Engines developed in recent years were more likely to use new technologies such as turbocharging, Atkinson-cycle design and rotary design, for which the air/fuel intake is not proportional with engine size. This exacerbates the issue that engine size is an imperfect proxy of other externalities.

Among these emerging engine technologies, turbocharging and supercharging are particularly problematic. These technologies could be used to downsize the engines and improve fuel economy, but they could also be used to increase power output at the expense of fuel economy while the engine size remains the same (Ross 1997). This gives automakers an opportunity to reduce engine sizes to benefit from the lower tax rate, but also adjust the engines using these technologies to compensate or even over-compensate for power loss, since consumers also attach real value to attributes such as power (Plotkin 2009). In this case, the expected improvement in fuel economy under engine size tax might then be compromised.

The second controversy is the cutoff method instead of continuous method used to differentiate tax rate differences. With the cutoff method, tax rates would change abruptly to a higher level when it crosses a threshold, instead of changing continuously when the attribute value increases.

Many attribute-based regulations are managed using a similar scheme. These cutoffs are likely to create distortions in the attributes. For example, Ito and Sallee (2017) found that such distortions are substantial in the case of weight-based fuel-economy regulations in Japan, since automakers can relatively easily respond to this policy by manipulating vehicle weight.

We are also interested in how this policy affects different manufacturers differently. This type of cutoff-based tax or regulation is also considered as a non-tariff trade barrier, since a government could formulate unique cutoffs so that the local market is quite different than other markets, while not adding particular tax to imported goods. Since the local manufacturer would usually have a bigger share of their total sales within their home region, they would be more willing to adapt to these taxes and regulations to take advantage of the cutoffs. In contrast, foreign manufacturers operating in that region often design their products according to global constraints, and it would be more difficult for them to make changes as rapidly.

In the case of Chinese automobile industry, even though the local market is still more important to domestic manufacturers than foreign manufacturers in terms of the share of sales in China, the market is probably big enough and important enough for many foreign automakers to make changes in response to the policies as well. However, they might be slower than their Chinese counterpart to complete the transition. Since many automakers design a limited number of engines and apply them to vehicle models in different countries, when they change engine sizes, they are also changing them in other markets. In many cases, the engines they use in China were previously developed for other markets first. The process may be slowed down by international cooperation between different branches of the company and marketing considerations for other countries. However, if they did end up designing engines for Chinese market conditions, those engines may also be later applied to vehicle models in other markets, depending on how similar vehicles sold in that market are to vehicles sold in China. Therefore, the impacts of the Chinese engine size tax would diffuse from China to other countries, creating difference in time and degree of change in different countries. We might also observe similar processes for other policies in other major markets. We want to investigate this process so that we can get a better understanding of the mechanism of the global impact of similar policies.

2.3. Literature Review

Existing studies of the Chinese automobile market often focuses on the demand-side. Wang and Yang (2008) investigated the relationship between brand personality, country-of-origin (COO) image and purchase intention, and found that both brand personality and COO image exert significant positive main effects on purchase intention.

There have been many studies predicting future automobile sales and ownership in China. Kung and Chang (2004) used Grey prediction model with data from 1995 to 2001 to forecast the sales and market share of the China automobile industry from 2002 to 2006. Huo and Wang (2012) used the Fuel Economy and Environmental Impacts (FEEI) model to project vehicle sales and stock in China. Wu et al (2014) forecasted the level of vehicle stock in China based on the extant patterns of vehicle development in Organization for Economic Co-operation and Development (OECD) countries.

Li et al (2016) estimated a market equilibrium model with differentiated multiproduct oligopoly using market-level sales data in China together with information from household surveys. They found that the decrease in markup from intensified competition accounts for about one third of this change and the rest comes from cost reductions. They also found that the price decline would have been larger had it not been for the growth of household income during this period.

Xiao and Ju (2014) used the model and simulation method of Berry, Levinson, and Pakes (1995) to obtain the equilibrium fuel consumption in a counterfactual experiment simulating the scenario in which the market structure remains the same as in 2008 while the vehicle consumption size tax and vehicle purchase tax revert back to those of 2006. They then compared this scenario with the facts pertaining to 2008. They found 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.

The last study mentioned above is particularly similar to this study since both investigate the impacts of engine size tax (vehicle consumption tax) on the China automobile market. However, this study differs in two ways: first, Xiao and Ju used model-level (eg. Honda Civic or Honda Fit) data while we used trim-level data (for example Honda Civic Comfort 1.0T or Honda Civic Luxury 1.5T). Since one vehicle model could have trims with different engines, trim-level data could better reveal the impacts on vehicles offered; second, we focus on the offering of the impacts on automakers while Xiao and Ju focus on impacts on consumers' choices.

3. Theoretical Framework

This study focuses on the impacts of the Chinese engine size tax policy on the supply side, and this section discusses the theoretical framework of how this tax affects decision making of manufacturers.

In general, a manufacturer makes decisions, for example setting the values for different attributes of a vehicle model, to maximize profits. Producing vehicles with bigger engines and more horsepower will increase the attractiveness and market performance of the model, but it will also increase production costs. Similarly, tradeoffs exist for other attributes. To maximize profits, the auto maker needs to choose optimal characteristics for the vehicles.

We first look at how profits are maximized for automakers. The total profit of a company is its total revenue minus its total cost, as shown in the following equation.

$$\pi(\alpha) = TR(\alpha) - TC(\alpha)$$

Where α is the set of attributes of the vehicle model produced by the manufacturer, $TR(\alpha)$ is the total revenue of the vehicle model, $TC(\alpha)$ is the development and production cost of the vehicle model. In detail, profit could be written in the following form:

$$\pi(\alpha, p^*(\alpha)) = p^*(\alpha) * q\big(\alpha, p^*(\alpha)\big) - \tau(\alpha > \bar{\alpha}) * q\big(\alpha, p^*(\alpha)\big) - TC\left(\alpha, q\big(\alpha, p^*(\alpha)\big)\right)$$

(1)

Where:

$p^*(\alpha)$ is the optimal price conditional on engine size α.

$q\big(\alpha, p^*(\alpha)\big)$ is the quantity produced given the engine size α and price p.

$\tau(\alpha > \bar{\alpha})$ is the engine tax rate the vehicle is subject to with the highest engine size cutoff below α.

$TC(\alpha, q\big(\alpha, p^*(\alpha)\big))$ is the total development and production cost of the vehicle model given vehicle engine size α and production quantity q.

The optimal α should be given by the following first-order condition of the above equation, based on which we could calculate the optimal engine size α^* that maximize profits.

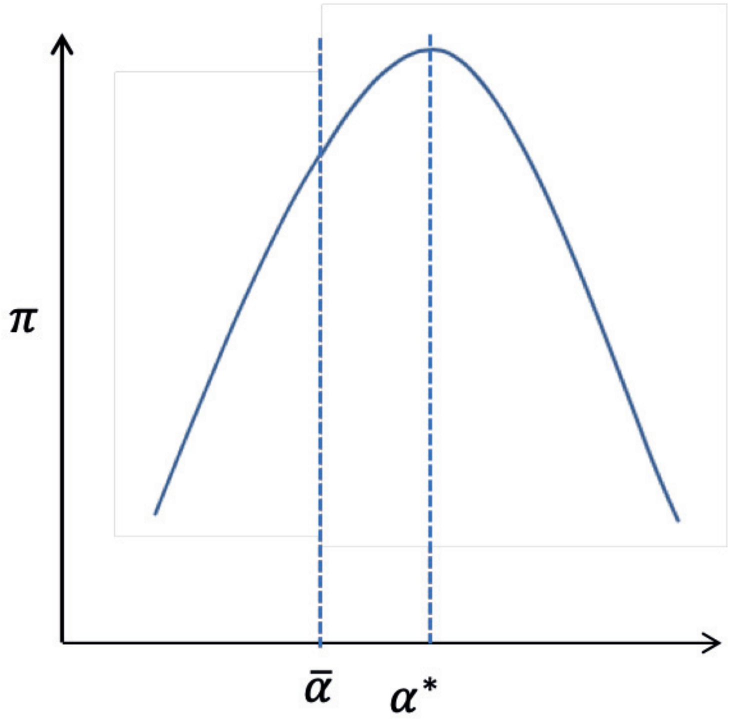
$$\frac{d\pi}{d\alpha} = (1 - \tau(\alpha > \bar{\alpha}))({p_{\alpha}}^{*\prime} * q + p^* * {q_{\alpha}}') - {TC_{\alpha}}'$$

(2)

We observe that $\bar{\alpha}$ changes in a discontinuous way when α changes. This creates a discontinuity in the profit-to-attribute mapping and thus creates a discontinuity in the optimal engine size α^*.

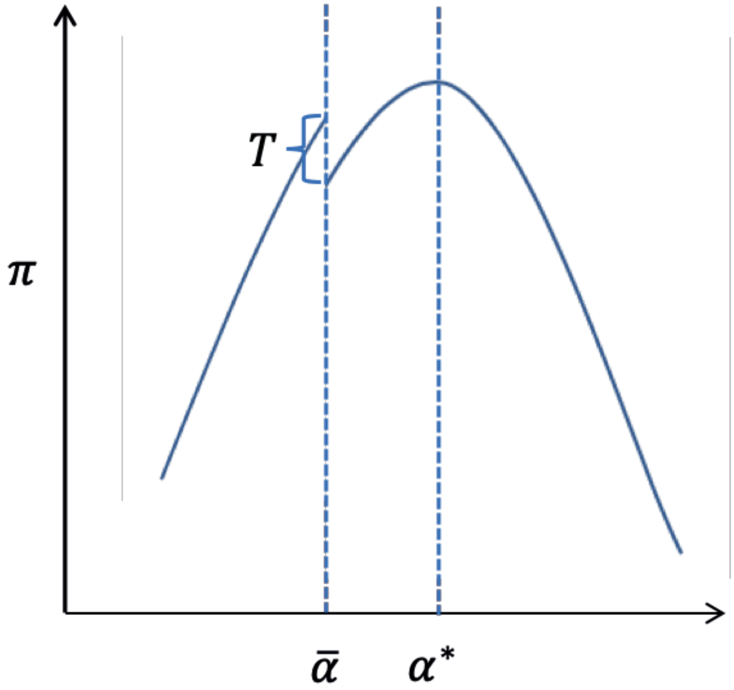
The following figures illustrates the impact of introducing engine tax rate $\tau(\bar{\alpha})$.

Figure 2.1: Original α^* with zero engine size tax rates (optimal engine size α^* above cutoff $\bar{\alpha}$)



As figure 2.1 shows, with no engine tax rates, the optimal engine size is α^*. If α^* is above the tax cutoff $\bar{\alpha}$, the tax rate change will affect the profit of the manufacturer, as illustrated in following figures.

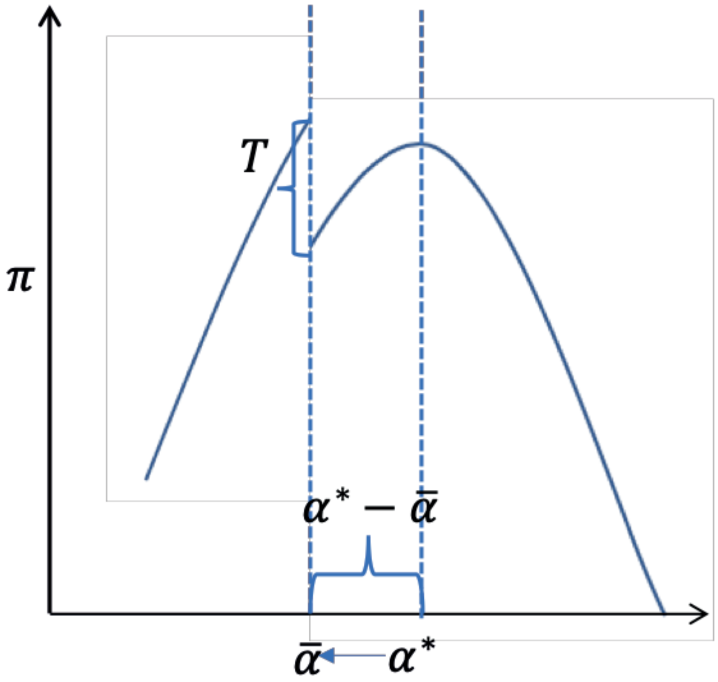
Figure 2.2: Optimal engine size α^* after engine size tax rates introduced.



As shown in figure 2.2, with engine size tax introduced, the part of the curve to the right of the engine size cutoff $\bar{\alpha}$ is α^* shifts downwards by T which is the engine size tax difference across the cutoff point. In this figure, the optimal engine size is still at α^*, since the tax difference T is not big enough and the difference between the original optimal engine size and the cutoff point below it, $\alpha^* - \bar{\alpha}$, is not small enough and the firm still maximize its profits at engine size α^*.

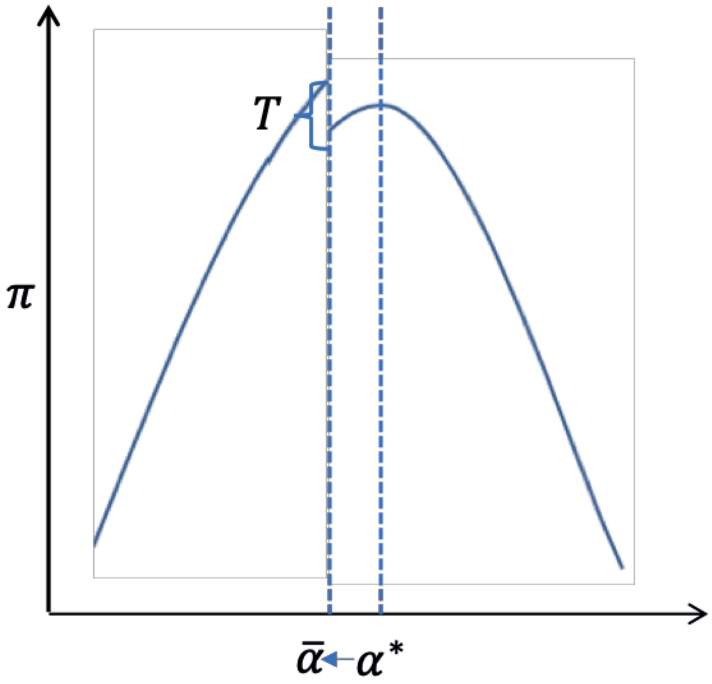
When tax rates are large enough, the tax difference T would be sufficient to move optimal engine size from α^* to $\bar{\alpha}$, as shown in figure 2.3.

Figure 2.3: Optimal engine size α^* moved to $\bar{\alpha}$ after engine size tax rates increased.



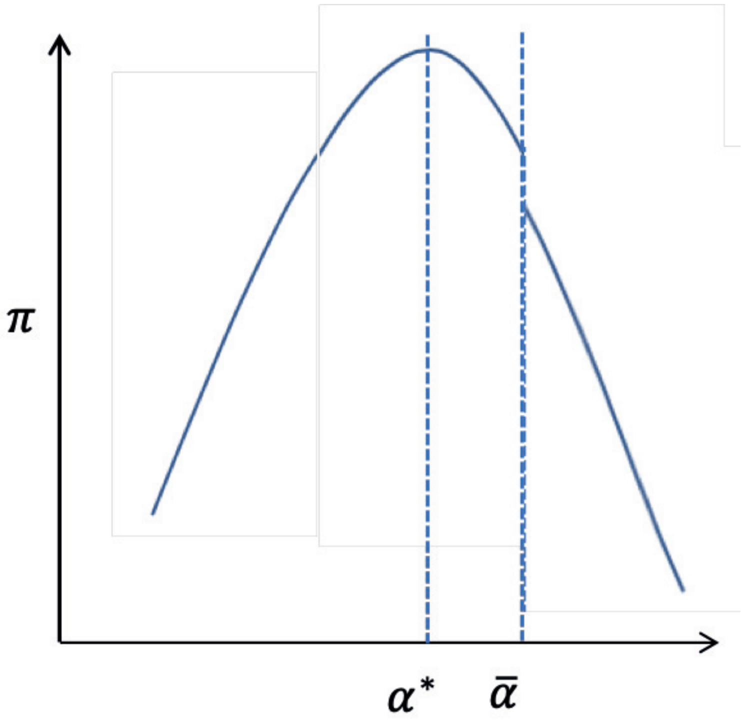
When the original optimal engine size is close enough to the cutoff point below it, a small tax difference T would also be sufficient to move optimal engine size from α^* to $\bar{\alpha}$, as shown in figure 2.4.

Figure 2.4: Optimal engine size α^* moved to $\bar{\alpha}$ when original optimal engine size is close enough to the cutoff point $\bar{\alpha}$.



It is also possible that the original optimal engine size was already below the tax cutoff. In this case, increasing tax rates for engine size above cutoff wouldn't affect future manufacturer choice, as shown in figure 2.5:

Figure 2.5: Original optimal engine size α^* below cutoff $\bar{\alpha}$



In summary, we learn:

- The engine size tax only affects manufacturer choice for vehicle models with previous selected engine size above the smallest tax cutoffs.
- Vehicle models with engine sizes above the cutoff and close to the cutoff are most likely to be affected.
- Larger tax rates increase the likelihood for engines to be downsized to cross the cutoffs.

Even though we do not observe the change in manufacturing cost, the change in vehicle characteristics offered by automakers is observed. We can then analyze the change in vehicle characteristics on the market with regard to the policy change, to learn about the impact of the policy.

The study uses several different regressions to analyze the decisions made by automakers during vehicle model updates. These regressions help to understand when engine sizes are modified to cross the cutoffs and benefit from a lower tax rate. We also ran regressions to learn about the effects on fuel efficiency on changes in engine size and engine technologies. Details are described in the following sections.

4. Data

4.1 Vehicle Trims

The analysis uses a vehicle specification dataset from 2004 to 2016 including data on vehicle dimensions, weight, fuel efficiency rating, engine horsepower and engine sizes. The dataset is retrieved using an Internet crawler computer program that we wrote to retrieve the specification data for all vehicle models and trims available on “Autohome,” the biggest online vehicle database in China. The dataset has 22,915 valid records (battery electric vehicles that do not have an internal combustion engine are excluded). Each record corresponds to a vehicle trim available on the Chinese market over the past two decades.

The statistical summaries of all vehicle trims offered between 2004 and 2016 are listed in the following tables:

Table 2.2: Statistical summary of major attributes of all vehicle trims in China 2004-2016

	Mean	Std. Dev.	Median
MSRP (Chinese Yuan)	319680	5707	136800
Fuel Consumption Rate (L/100km)	6.3	0.0243	7.1
Power (kw)	121.9	0.428	104.0
Engine Size (L)	2.06	0.00564	1.83
Weight (kg)	1311	3.89	1402
Length (m)	4.59	0.00277	4.60
Width (m)	1.79	0.00067	1.80
Height (m)	1.59	0.00112	1.52
Wheelbase (m)	2.72	0.00178	2.70

Note: MSRP stands for manufacturer's suggested retail price

As we can see from the above table, a typical vehicle sold in China is a compact sedan that is priced around 136,800 Chinese Yuan (or 20,000 US dollars). The average size, power, and price are lower than the average passenger vehicle sold in the United States. The mean and median fuel consumption rate translate to 37 and 33 Miles Per Gallon respectively. However, the official ratings in the two countries cannot be directly compared, since China uses a test cycle similar to the NEDC test cycle used in Europe, which is not as realistic in reflecting real-world driving situations as the US06 test cycle used by the Environmental Protection Agency in the United States (Lancaster 2017).

The distribution of the engine sizes of the vehicle trims is shown in the following table:

Table 2.3: Distribution of the engine sizes of all vehicle trims in China 2004-2016

Engine Size	Count	Percentage
>4	796	3.5%
3-4	950	4.1%
2.5-3	2079	9.1%
2-2.5	2846	12.4%
1.5-2	9781	42.7%
1-1.5	5854	25.5%
<=1	609	2.7%
Total	22915	100.0%

As we can see from the table, most vehicles sold in China have engines sized between 1 and 3 litres with nearly half of the vehicles sized between 1.5 and 2 litres. In general vehicle engines are much smaller in China compared with the United States.

The distribution of vehicle trims manufactured by Chinese automakers, foreign automakers that produce vehicles through joint ventures in China, and automakers abroad is listed as below:

Table 2.4: Distribution of manufacturer type in China

Manufacturer Type	Percentage of All Offered Trims 2004-2016	Market Share in 2016

Chinese	45.2%	43.2%
Joint Venture	34.0%	52.5%
Imports	20.8%	4.35%

As we can see, most of the vehicles offered and sold in China are made by Chinese automakers or joint ventures.

The median values of the major attributes are listed in the following table:

Table 2.5: Comparison of major attributes of manufacturer type of all vehicle trims in China 2004-2016

	Chinese	Joint Venture	Imports
MSRP (Chinese Yuan)	8.79	16.98	51.97
Fuel Consumption Rate (L/100km)	6.8	7.2	8.1
Power (kw)	89	108	177
Engine Size (L)	1598	1798	2498
Weight (kg)	1320	1395	1635
Length (m)	4570	4582	4729
Width (m)	1780	1798	1864
Height (m)	1680	1483	1500
Wheelbase (m)	2685	2685	2780

Note: MSRP stands for manufacturer's suggested retail price

We can see that the median length, width and wheelbase are very similar for Chinese automakers and joint ventures. The median height of vehicles made by Chinese automakers is higher, since they make more SUVs and vans than joint ventures. The median fuel consumption rate is higher for Chinese automakers, as a result of their products being lighter and less powerful. The vehicles made by Chinese automakers are also much cheaper than those made by joint ventures. The imported vehicles are bigger, more powerful, and more expensive than those of the Chinese automakers and joint ventures.

4.2 Model Redesigns

Part of this study involves identifying the major updates, or model redesigns of a vehicle model. Most vehicle models are updated based on a "generation" concept. Every 5 to 7 years, automakers redesigns the vehicle, with a new chassis, new body, and new or improved powertrain. Within the period for one generation, the vehicle model may also get one or two "facelifts", slightly changing the original design of the current generation. If automakers in China want to downsize the engine to a different tax category, these major model updates would be an opportunity to change engines. By comparing the wheelbase of a vehicle model in a certain model year with the previous model, we are able to identify when the models are redesigned.

Regarding model redesigns, we only use the base trims of vehicle models. By comparing the wheelbase of a vehicle model in a certain model year with the previous model, we are able to identify 299 model redesigns. The statistical summaries of model redesigns are listed in the following tables:

Table 2.6: Statistical summary of major attributes after model redesigns in China 2004-2016

	Mean	Std. Dev.	Median
MSRP (Chinese Yuan)	483,243	762,844	251,200
Fuel Consumption Rate (L/100km)	6.60	3.79	6.90
Power (kw)	144	69	110
Engine Size (L)	2.32	1.01	2.00
Weight (kg)	1311	665	1466
Length (m)	4.69	0.43	4.71
Width (m)	1.82	0.13	1.82
Height (m)	1.55	0.19	1.48
Wheelbase (m)	2.75	0.41	2.76

Note: MSRP stands for manufacturer's suggested retail price

The distribution of the engine sizes of model redesigns is shown in the following table. The table uses engine sizes before rather than after the model redesigns to show what engine sizes are redesigned.

Table 2.7: Distribution of the engine sizes before model redesigns in China 2004-2016

Engine Size	Count	Percentage
>4	26	8.7%
3-4	22	7.4%
2.5-3	44	14.7%
2-2.5	42	14.0%
1.5-2	126	42.1%
1-1.5	37	12.4%
<=1	2	0.7%
Total	299	100.0%

Table 2.8: Comparison of major attributes of manufacturer type after model redesigns in China 2004-2016

	Chinese	Joint Venture	Imports
Proportion	20.7%	27.4%	51.8%
MSRP (Chinese Yuan)	7.89	17.93	45.89
Fuel Consumption Rate (L/100km)	7.30	7.30	8.10
Power (kw)	88	112	156
Engine Size (L)	2.00	1.60	2.36
Weight (kg)	1328	1290	1592
Length (m)	4.67	4.65	4.74
Width (m)	1.76	1.82	1.85
Height (m)	1.70	1.47	1.48
Wheelbase (m)	2.72	2.70	2.78

As we can see from the table, the redesigned vehicle trims are generally much bigger, much more powerful and much more expensive than the typical vehicle trims offered on the market. Imported vehicles are also more likely to get model redesigns.

5. Impacts of Engine Size Tax on Vehicle Attributes in China

5.1 Timing of Policy-Induced Engine Size Change

We first want to test whether this policy has actually encouraged engine downsizing and when the engine downsizing happened. In this analysis, we examine the engine sizes of all the trims available on the Chinese market from 2004 to 2016. The specification is shown as follows:

$$ES_{jky} = \alpha + \beta t_y + \gamma_1 post2006_y + \gamma_2 post2008_y + \varepsilon_{jky}$$

Where,

ES_{jy} is the engine size for vehicle *j* trim *k* in model year *y*.

t_y is the time trend variable;

ε_{jky} is an error term.

$post2006_y$ and $post2008_y$ are dummy variables indicating whether the trim entered the market after the policy change in April 2006 or August 2008. Since automakers are not able to modify engines immediately after the policy change, in a second version of this regression, we changed $post2006_y$ and $post2008_y$ to $engine\_post2006_y$ and $engine\_post2008_y$. This compares the first introduction of the same engine (with identical size and horsepower) on a particular model with the time of policy change. For example, $post2006_y$ and $post2008_y$ are both equal to 1 for a vehicle trim produced in 2009. However, if the engine was first introduced in 2007, only $post2006_y$ is 1 and $post2008_y$ would be 0.

ε_{jky} is an error term.

The results are shown in the following table:

Table 2.9: Regression results analyzing engine sizes of vehicle trims in different model years

Engine size (litres)	(1)	(2)	(3)
Constant term	2.304*** (.0198)	2.300*** (.0228)	2.291 ** (.0209)
t (years after 2004)	-.00173*** (.000133)	-.00161*** (.000202)	-.00158** (.000196)
Model Year After 2006		-.0103 (.0315)	
Model Year After 2008		-.0269 (.0282)	
Engine Designed After 2006			.0302 (.0259)
Engine Designed After 2008			-.0449* (.0234)
R-Squared	.0074	.0074	.0075
N	22917	22917	22917

Note:

1. *, ** and *** denote significance at the 5% 1% and 0.1% levels.
2. Standard errors are reported in parentheses.
3. The dependent variable in all columns is the engine size.

The estimated coefficients of *t* are negative in all three regressions. Therefore, we observe that vehicles in China have been consistently downsized within the period 2004 to 2016.

When model year dummies are included, the estimated coefficients are insignificant. Apparently, if the vehicle is offered after the policy change, but the engine has not been redesigned yet, its size wouldn’t have a chance to be changed.

However, there was no significant difference before or after the policy change in 2006. The engines introduced after the 2008 policy change are more likely to be further downsized. However, considering the 2008 policy change only targets engines bigger than 3 litres and smaller than 1 litre and most of the vehicles sold in China have engine sizes between 1 and 3 litres, it is unclear whether this expedited downsizing was caused by the policy change. After all, the steps for different tax rates are quite big (0.5 litres), so it is not easy for vehicle models to cross the tax threshold repeatedly with each redesign.

The constant terms all have positive coefficients, showing that the engines were downsized, regardless of policy changes.

5.2 Model Redesigns and Whether Cutoffs are crossed

The results from the previous section shows that engine size tax only took effect when vehicle models are redesigned. Therefore, we want to focus on model redesigns to see exactly how the engine size tax affected the supply of vehicle models in China. In the second to fourth section of the regression analysis, we first look at how tax rates affect the probability of crossing the cutoffs, then investigate what changes in engine technology are associated with crossing tax cutoffs, and finally how these changes in engine technology affect fuel consumption rates.

The method we used to identify the model redesigns were described in the data section. After identifying the model redesigns, we can then investigate how engine-related changes are made during these redesigns. We start by investigating which factors are correlated with manufacturers downsizing the engines to cross the tax cutoffs, to help understand the magnitude of the impacts related to increases in the tax rate.

Based on the previously described theory in the theoretical framework section, we predict that automakers are more likely to downsize the engine to a lower tax category if the costs of doing so is lower, indicated by variables such as proximity of current engine size to the next lower tax cutoff size, or when the benefits of doing so is higher, indicated by savings from the engine tax. To test these hypotheses, we use the following specification:

$$c_{jy} = \alpha + \beta \underset{Y_{jy}}{\rightarrow} + \varepsilon_{jy}$$

Where,

c_{jy} is a dummy variable indicating whether or not a vehicle *j* in model year y has downsized the engine to a lower tax category (we name this event as "cutoff crossed") compared with the previous model year in a model redesign.

$\underset{Y_{jy}}{\rightarrow}$ are changes the model makes if it did cross cutoffs, including how much the engines must downsize, and what the engine size tax benefits are. They are measured in both relative and absolute terms. Downsizing an engine needs are measured by both the "downward engine size difference" and the "downward difference as a proportion of current engine size", which are defined as follows. If an engine size is currently 1.8 litres and the current engine size tax rate is 5%, the engine size needs to be reduced by 0.3 litres to be subject to a lower tax rate of 3%. The downward engine size difference in this case is 0.3 litres, while the “downward difference as proportion of current engine size” is 0.3L/1.8L=16.7%. The vehicle consumption tax benefits are measured by “potential reduction in vehicle consumption tax rate” and “potential vehicle consumption tax savings”. For example, if the vehicle is currently priced at ￥150,000. With a 1.8 litre engine, the vehicle consumption tax rate is 5%. The tax is ￥150,000*5%=￥7,500. If the engine is downsized to 1.5 litre for the next model year, the vehicle consumption tax rate would be reduced to 3%. The tax would be ￥150,000*3%=￥4,500. In this case, the potential reduction in vehicle consumption tax rate is 5%-3%=2%. The potential vehicle consumption tax savings is ￥150,000*2%=￥3,000. The price of the previous model year is used to calculate the tax savings.

ε_{jy} is an error term.

Table 2.10: Regression results on whether a cutoff is crossed

Cutoff crossed	(1)	(2)	(3)	(4)	(5)
Constant term	.288*** (.052)	.175*** (0.035)	.272*** (.058)	.376*** (.048)	.259*** (.038)
Downward difference as proportion of current engine size	-.908*** (.217)		-.738** (.35)	-.965*** (.23)	
Downward engine size difference (L)		-.227*** (.063)	-.0626 (.99)		-.161*** (.078)
Potential reduction in engine size tax rate	2.18*** (.53)	3.35*** (.63)	2.51** (.74)		
Potential savings in engine size tax (Chinese Yuan ￥)				.00347 (.0022)	.00634** (.0032)
R-Squared	.1034	.0515	.1046	.0598	.0162
N	184	184	184	184	184

Note:

1. *, ** and *** denote significance at the 5% 1% and 0.1% levels.
2. Standard errors are reported in parentheses.
3. The dependent variable in all columns is whether tax cutoffs are crossed in model updates.

The results of regression (1) show that the likelihood of crossing cutoffs is negatively correlated with distance from the cutoff as a proportion of current engine size, and is positively correlated with potential reductions in engine size tax rate. This means that the more the engine needs to be downsized (higher cost for the company), the less likely the engine will be downsized to cross the cutoff. In contrast, with a bigger reduction in tax rate (more benefits for crossing the cutoff), it becomes more likely that the engine will be downsized to fall into the lower tax category.

The regressions (2) and (3) compare the effect of absolute downward engine size difference with the proportional difference. When both variables are included in the specification, only the downward difference as a proportion of current engine size appears to be significant. The coefficient for downward engine size difference is relatively smaller than the coefficient for downward difference as a proportion of current engine size when only one of them is included in the specification. The coefficients are -0.738 and -0.0626 respectively, the factor of 30 difference indicates that the absolute difference is not as important. For example, a 1.8 litre engine has a proportional downward difference of 0.123. This decreases the likelihood of crossing the cutoff by 0.195. However, the absolute downward difference is 0.3, this decreases the likelihood of crossing the cutoff by only 0.01045, which is much smaller than 0.195. This indicates that the relative engine size distance from the cutoff has more impact on the likeliness of downsizing, as downsizing by 0.4 liter for a 4.0 litre engine might be easier than downsizing by 0.4 liter for a 1.5 litre engine.

However, the downward engine size difference still appears to be significant when included as the sole variable in the specification; we cannot rule out the possibility that the absolute difference has an effect automakers' decisions.

Regressions (4) and (5) replace the potential reduction in vehicle consumption tax rate with potential vehicle consumption tax savings. The coefficient for tax savings in regression (4) is insignificant, showing that the absolute savings in tax doesn't have a corresponding effect. Although the same coefficient in regression (5) appears to be significant, it is still very small. For a vehicle priced at ￥200,000, a tax rate cut of 4% means tax savings of ￥8,000. This only increases likelihood of crossing the cutoff by 0.008*0.634=0.005, based on column (5) results. By contrast, using results from column (2), the 4% reduction in tax rate is correlated with an 0.04*3.35=0.134 increase in likelihood of crossing the cutoff. Besides, the R-squared for column (5) is also very small for this specification. If absolute tax savings do motivate automakers to cross tax cutoffs, this is only the case for very expensive vehicles.

In conclusion, the relative engine size distance from the cutoff and the engine size the reduction in tax rate have more significant impacts on whether the manufacturer downsized the engine to cross the cutoffs.

5.3 Impacts of Crossing Cutoffs on Engine Technology

In the next step, we want to explore whether the policy also encourages other changes to the engine, including whether that induces the introduction of turbocharging/supercharging technologies, and how much engine size reduction is correlated with crossing the cutoffs. We also focus on model redesigns in this section to investigate what happens during major updates of the vehicle (engine changes are not likely to happen with minor updates).

The first hypothesis is that engine size tax cutoffs might induce turbocharging/supercharging. When the original engine size is much bigger than the next smaller cutoff, the manufacturer might have to change from natural aspirated engines to turbocharged/supercharged engine to downsize the engine while not reducing the power output. The following specification is used to test this hypothesis:

$$AI_{jy} = \alpha + \beta \underset{Y_{jy}}{\rightarrow} + \varepsilon_{jy}$$

Where,

AI_{jy} is a dummy variable indicating whether the air intake technology of the engine changes from natural aspiration to turbocharging or supercharging (1 indicates that a vehicle model is turbocharged/supercharged while in the previous model year it was naturally aspirated)

$\underset{Y_{jy}}{\rightarrow}$ are other changes the model makes in the model update. This includes whether the engine crossed the cutoffs (1 indicates that a cutoff point is crossed), and the change in engine size.

ε_{jy} is an error term.

Results are shown in the following table:

Table 2.11: Regression results analyzing change in engine technology after model updates

Become Turbocharged/Supercharged	(1)	(2)
Constant term	.020** (.0155)	.020** (.0155)
Cutoffs crossed	.094** (.035)	.107** (.050)
Change in engine size (L)		.020 (.053)
R-Squared	.0373	.0381
N	184	184

Note:

1. *, ** and *** denote significance at the 5% 1% and 0.1% levels.
2. Standard errors are reported in parentheses.
3. The dependent variable in all columns is whether engine technology shifted from naturally aspirated to turbocharged or supercharged in model updates.

What interests us is, crossing cutoffs is positively correlated with implementation of turbocharging/supercharging, while changes in engine size is insignificant. This might indicate that attempting to downsize the engine itself is not a strong factor influencing automakers to introduce turbocharging/supercharging. In contrast, when there is a specific cutoff to cross associated with savings in tax, automakers are much more likely to shift towards turbocharging/supercharging. In other words, we find that the current cutoff-based tax scheme induced turbocharging and supercharging, which increases fuel consumption rate.

The second direction of the impact of crossing the cutoffs is from a change in the engine size. If the cutoff is crossed from above, the engine is downsized. Here we can test how much engine downsizing is associated with crossing the cutoff. We use the following specification

$$\Delta ES_{jy} = \alpha + \beta \underset{Y_{jy}}{\rightarrow} + \varepsilon_{jy}$$

Where,

$\Delta ES_{jy}$is a variable measuring the change in engine size, measured by engine size after model updates minus engine size before model updates.

$\underset{Y_{jy}}{\rightarrow}$ are other changes the model makes in the model update. This includes whether the engine is downsized enough to cross the cutoffs (1 indicates that a cutoff point has been crossed), and whether the air intake technology of the engine has changed from natural aspiration to turbocharging or supercharging (1 indicates that a vehicle model is turbocharged/supercharged while the previous model year it was naturally aspirated).

ε_{jy} is an error term.

Results are shown in the following table:

Table 2.12: Regression results analyzing change in engine size after model updates

Engine Size Change	(1)	(2)
Constant term	-.0110** (23.4)	-.0118*** (23.4)
Cutoffs crossed	-.658*** (51.4)	-.662*** (51.4)
Become Turbocharged/Supercharged		-.0398 (.105)
R-Squared	.4866	.4870
N	184	184

Note:

1. *, ** and *** denote significance at the 5% 1% and 0.1% levels.
2. Standard errors are reported in parentheses.
3. The dependent variable in all columns is the engine size change, measured by engine size after model updates minus engine size before model updates.

We can see from the results (1) that, when cutoff is crossed, on average the engine size is reduced by 0.658 litres. Results (2) show again that when whether cutoff is crossed is controlled, whether the engine become turbocharged/supercharged is not correlated with engine downsizing.

Again, constant terms are negative, showing that the engines were downsized, no matter how close the previous engine size were to cutoffs and whether the air intake technology were changed.

5.4 Impacts on Fuel Consumption Rates

In the final step, we learn how crossing tax rate cutoffs affects the fuel consumption rate, i.e. whether the policy has achieved its intended goal of reducing fuel consumption.

As the results in the previous section reveal, crossing the tax cutoff is often associated with two changes in engines: engine downsizing and turbocharging/supercharging. As discussed in the background section, engine downsizing generally reduces fuel consumption rate. Therefore, we expect reduction in engine size to have a positive correlation with reduction in fuel consumption rates.

Turbocharging/supercharging the engine could be an effective method to reduce fuel consumption: the technology is used to downsize engines and achieve the same power output with much smaller engines. However, given a constant engine size, turbocharging and supercharging increases the air intake capacity of engines and thus increases power output and fuel consumption. Therefore, after controlling for engine size, we expect using these technologies would negatively affect fuel consumption reduction. This set of regressions are based on the following specification:

$$\Delta FC_{jy} = \alpha + \beta \overset{\rightarrow}{Y_{jy}} + \varepsilon_{jy}$$

Where,

$\Delta FC_{jy}$is a variable measuring the change in fuel consumption rate (based on the Chinese official fuel economy rating in units of litre of gasoline consumed per 100 kilometers of driving) of vehicle *j* in model year *y* compared with the previous model year in a model redesign.

$\overset{\rightarrow}{Y_{jy}}$ are other changes the model makes in the model update. This includes how much the engine size changes, whether the engine is downsized enough to cross the cutoffs (1 indicates that a cutoff point has been crossed), and whether the air intake technology of the engine has changed from natural aspiration to turbocharging or supercharging (1 indicates that a vehicle model is turbocharged/supercharged while the previous model year it was naturally aspirated).

ε_{jy} is an error term.

For the regression exploring the impacts of engine downsizing, crossing tax rate cutoffs, and turbocharging/super charging the engine on the fuel consumption rate, the results are shown in the following table:

Table 2.13: Regression results analyzing change in fuel consumption rate after model updates

Reduction in fuel consumption rate (L/100km)	(1)	(2)	(3)	(4)
Constant term	.512*** (.094)	.533*** (0.086)	.552*** (.090)	.572** (.081)
Cutoffs crossed	.914*** (.216)	-.259 (.275)	1.10*** (.209)	-.054 (.263)
Reduction in engine size (L)		1.78*** (.292)		1.74*** (.275)
Become turbocharged/supercharged (change in air intake technology)			-1.98*** (.428)	-1.91*** (.389)
R-Squared	.0895	.2450	.1856	.3345
N	184	184	184	184

Note:

1. *, ** and *** denote significance at the 5% 1% and 0.1% levels.
2. Standard errors are reported in parentheses.
3. The dependent variable in all columns is change in fuel consumption rates, measured by fuel consumption rates after model updates minus fuel consumption rates before model updates.

The results of regression (1) show that redesigned vehicles in general had a reduced fuel consumption rate. When cutoff points are crossed, there is a 0.914L/100km reduction in fuel consumption rate. However, previous analysis in this paper indicates that on the one hand, the engine size tax cutoffs induce engine downsizing, which help to reduce fuel consumption rate. On the other hand, it induces turbocharging/supercharging, which increases fuel consumption rates when isolated from engine downsizing. Further investigation is needed to determine the actual impacts of tax cutoffs.

The results of regression (2) clearly show that the reduction in fuel consumption rate is positively correlated with the reduction in engine size. This means that downsizing the engine in general did help to reduce fuel consumption rate. When we control for crossing the cutoff, every 1 litre reduction in engine size is associated with a 1.78L/100km reduction in fuel consumption rate.

Regression (2) also shows that with change in engine size controlled, whether the engine has crossed a cutoff point is not significant. Since the cutoff points are artificially set, it is indeed not likely to have special impact on the fuel consumption rate. Downsizing an engine crossing cutoff points like 2.0 litre and 1.5 litre should not yield more benefit in fuel consumption rate than a downsizing crossing other values like 1.9 litre or 1.45 litre. On the other hand, the fact that the coefficient has turned negative probably shows that crossing the cutoffs is related with some factors that *increase* fuel consumption rate.

As column (3) shows, when the engine shifts from naturally aspirated to turbocharged or supercharged (or there is a change in air intake technology), the coefficient on the dummy variable indicating change in engine air intake technology is positive. This means that crossing of the cutoffs is controlled for, shifting towards turbocharging or supercharging increases fuel consumption rate, as expected.

Regression (4) includes all three variables and further tests the correlation between the introduction of turbocharging/supercharging and fuel efficiency for redesigned vehicle models in China. We find that a reduction in engine size positively affects fuel consumption reduction and turbocharging/supercharging negatively affects fuel consumption reduction, regardless of cutoffs being crossed.

In summary, the tax cutoffs induce two changes in engine technology: engine downsizing which positively contribute to fuel consumption reduction, and application of turbocharging/supercharging which positively contribute to fuel consumption reduction. The latter outweighs the positive effect of the former one on reducing the fuel consumption rate. If a continuous engine size tax (as opposed to a tax based on cutoffs) is used instead to avoid encouraging aggressive engine downsizing, or if the engine size tax set special tax rate calculation for turbocharged/supercharged engines, the latter effect may be removed or reduced, and fuel consumption rate could be further reduced.

5.5 Evaluating the Effects of Engine Size Tax on Fuel Consumption Saving

Based on the regression results in the previous sections. We perform some back-of-envelope calculations of the effects of tax changes and evaluate this policy.

In the data section, the mean engine size of vehicles offered in China is 1.83 litre. The highest cutoff point below it was 1.5 litre. Before 2006, there was no difference in tax rate above or below

1.5 litre. After the tax rates were changed in 2006, there has been a 2% difference in tax rate.

Using results of column (1) from section 5.2, we can calculate that the likelihood of crossing the cutoffs is increased by 2.18*0.02=0.0436 from the counterfactual situation where tax rate is not increased.

Using results of column (1) from section 5.4, we can calculate that a 0.0436 increase in likelihood of crossing the cutoff would bring fuel consumption rate down by an additional 0.0436*0.914L/100km=0.0399L/100km (in addition to status quo increase).

On average, passenger cars are driven 11,500 kilometers annually in Beijing.[32] If this were to represent the national average (national data not available) and vehicles were assumed to have a 10-year average life span, this would translate to 45.8 litres of reduction in gasoline consumption.

In the past 13 years from 2006 to 2018, there were 199.2 million passenger vehicles sold in China[33]. If we conservatively assume that all the vehicles sold were like the median car (for bigger vehicle the tax rate difference was larger and should induce higher likelihood of crossing the cutoff and more reduction in gasoline consumption), the total reduction in gasoline consumption would be 9.13 billion litres of gasoline, which is 57.54 million barrels of oil equivalent ,[34] or 5.754 million tons of oil equivalent annually, assuming a lifespan of 10 years for each vehicle.

In comparison, the total oil consumption in 2018 in China is 4.581 billion barrels.[35] The 5.754

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[32] 2015 年北京交通发展年报(2015 Beijing Transportation Development Annual Report), Beijing Transportation Development and Research Center, March 3, 2016.

[33] China Passenger Car Association

[34] The Society of Petroleum Engineers, https://www.spe.org/industry/docs/UnitConversion.pdf

[35] 2018 Domestic and International Oil and Gas Industry Development Report， China National Petroleum Corporation Economic and Technological Research Institute

million barrels reduction is 0.18% of the total national oil consumption.

The above calculation is solely based on the impacts of the engine size tax on vehicle supply. However, the policy could also change the vehicle mix, as the vehicle models that did downsize to cross the tax cutoffs could sell better than the ones that do not, with the advantage in fuel efficiency. Using the results from chapter three of this dissertation, we know that the sales of a vehicle model is 1.6 percent higher if its fuel efficiency is 1 percent better. This 0.914L/100km reduction in fuel consumption rates therefore translates to its sales rising by 12.9%. Therefore, the average reduction in fuel consumption rate on the supply side is 12.9% more on the demand side. The oil consumption would be instead 6.494 million tons annually, which is 2.03% of the national consumption.

We could also evaluate this effect in the perspective of cost of carbon emission reduction. For 64.94 million barrels of gasoline consumption reduction in the entire lifespan for these vehicles, the corresponding carbon dioxide emission reduction is 27.9 million metric tons, based on carbon dioxide emission per gallon of gasoline burnt[36]. Based on the mean price of vehicles sold in China and the 2% increase in tax rates, the cost of the tax is US$77 billion over the last 13 years. Therefore, the cost of carbon dioxide emission reduction per ton is $2,766, which is unusually high.[37] In comparison, policies like the CAFE standards that also aims at improving average vehicle fuel efficiency, only has $106 cost per ton of carbon emission reduction (Krupnick et al 1993).

However, if the turbocharging/supercharging shifts could be avoided, the effects could be

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[36] Physical and chemical properties of gasoline: Department of Energy (DOE), Alternative Fuels Data Center (AFDC), Properties of Fuels.

[37] See Chapter 3

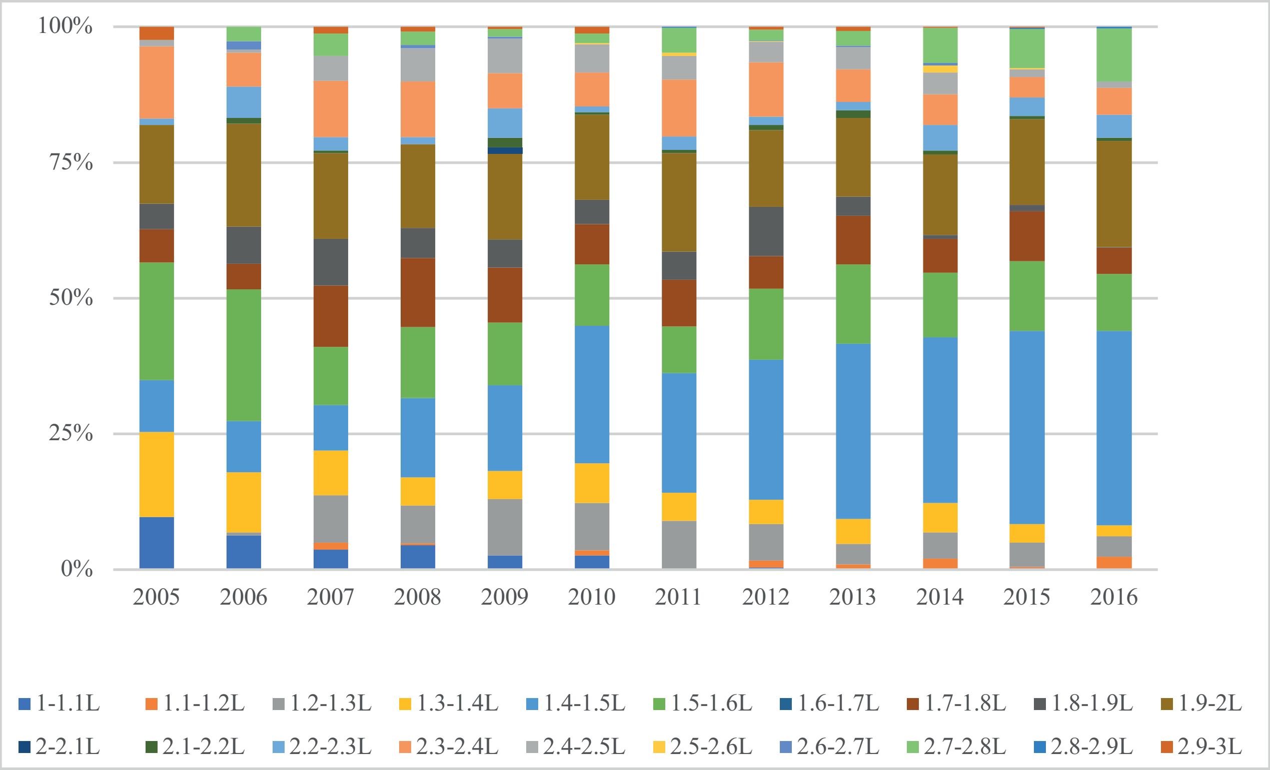
better. Using the results from column (2) of latter part from section 5.3, we know that a 0.0436 increase in likelihood of crossing the cutoff is associated with a 0.0289 litre reduction in engine size in addition to the counter factual status quo. This again translates to a 0.0499 litre/100km reduction in fuel consumption, without turbocharging/supercharging compromising the effects. This increase of reduction in fuel consumption rate means 25.3% more fuel consumption reduction than the previous calculation. The cost of carbon dioxide emission reduction per ton could also be reduced to $2,207. This number is still much bigger than fuel economy standards. However, the engine size tax in China may not be designed particularly to reduce fuel consumption or carbon emission in the most efficient way. They policy might be designed as a luxury tax or a tax to reduce vehicle size, or just generate revenue for government in the first place. Reducing fuel consumption or carbon emission might only be one of the goals.

6. Impact of the Policy Change on Different Manufacturers.

The last section of the study focuses on the impact of the policy change on different manufacturers. Based on previously described theory, there should be a higher proportion of engines sized right above the tax rate cutoffs. However, the impact might be different for Chinese and foreign automakers since they are affected differently by conditions in other markets.

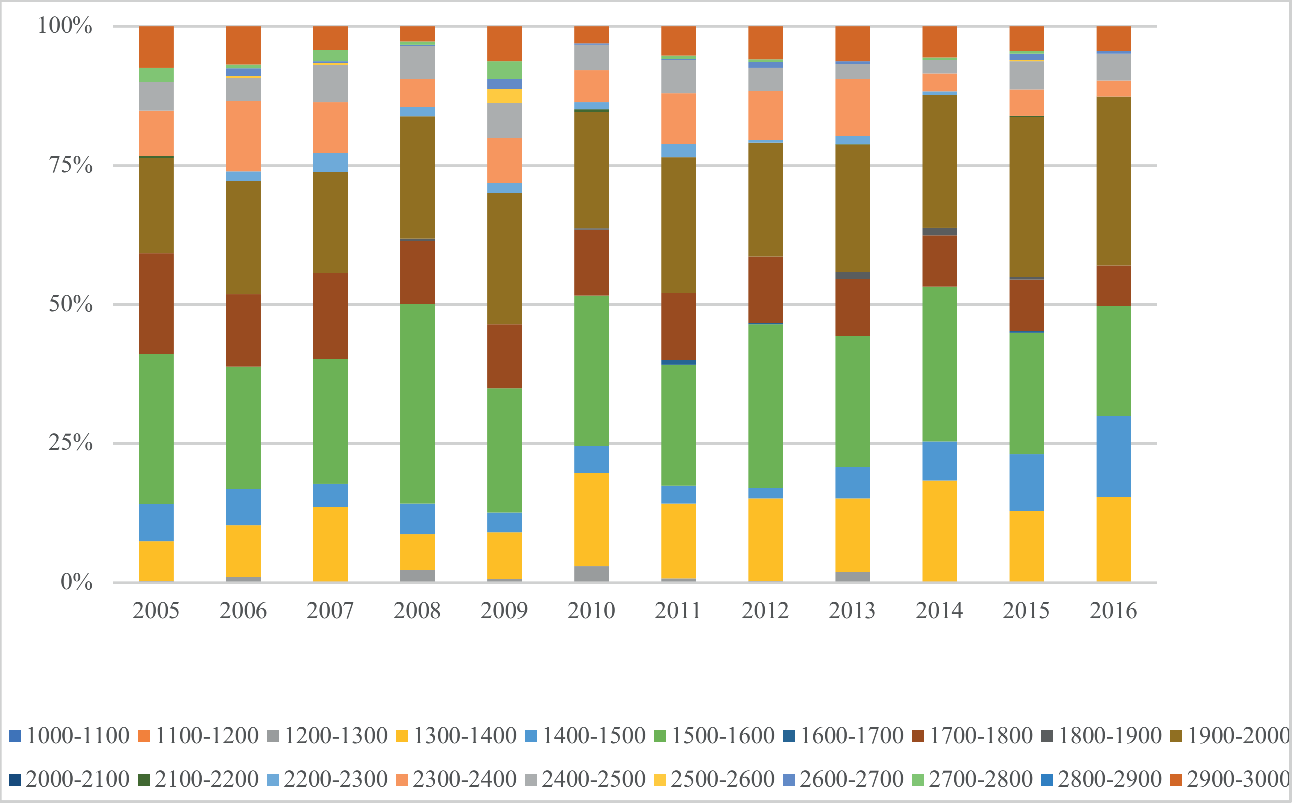
With the specification data at the trim-level, we observe a pattern of engine size clustering around cutoff points. However, Chinese manufactures adjust to the policy change faster than joint ventures (foreign brands that manufacture automobiles in China through partnership with local corporations). They shifted the engine sizes right below the cutoff faster following the policy change. This is shown in the following two graphs describing the change in distribution of different engine sizes over time for Chinese brands and foreign brands that produce in China.

Figure 2.6: Change in engine size (in litres) distributions for vehicle trims manufactured by Chinese automakers from 2005 to 2016



Note: Heights correspond to the share of different engine size bands among vehicle trims offered by Chinese manufacturers.

Figure 2.7: Change in engine size (in cubic centimeters) distributions for vehicle trims manufactured by joint venture automakers from 2005 to 2016

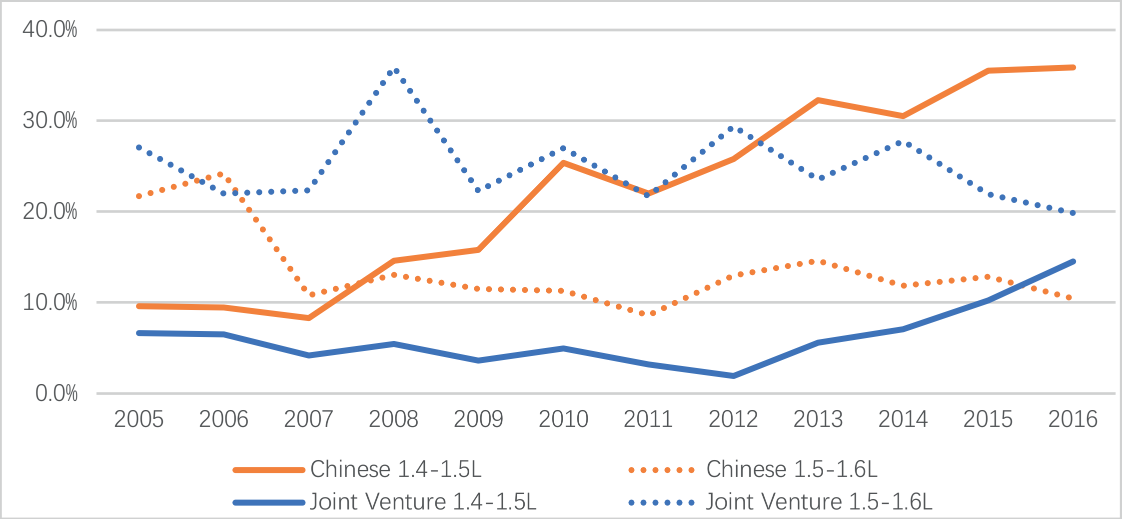


Note: Heights correspond to the share of different engine size bands among vehicle trims offered by joint venture manufacturers.

The two graphs focus on the vehicle trims with engine sizes between 1 and 3 litres. This includes the market segments where most vehicles are sold. It is also the only range that was affected by the policy change in 2006. In these two graphs, we can see that the share of engines in the categories of 1300-1400cc and 1500-1600cc quickly shrank, while the share of engines between 1400cc and 1500cc quickly increased. The share of 1900-2000cc engines also increased by a bit. On the other hand, even though both the shares of 1400-1500cc and 1900-2000cc engines also increased for the joint ventures, the change is much smaller for the 1400-1500cc share. Foreign brands still manufacture a significant amount of 1300-1400cc and 1500-1600cc engines, with the latter increasing over time. This is probably related with some other countries still using 1400cc and 1600cc as cutoffs for tax and regulations. When some foreign automakers downsized their engines into the 1000-1500cc tax category, they downsized to 1.4 litre instead of 1.5 litre. Therefore, they are not able to fully utilize the upper boundary of the category, facing a disadvantage in the competition with Chinese automakers.

The following figures look at the trend of shares of engine sizes around the most typical 1.5L in China. It also shows that Chinese automakers were faster to respond to the tax rate change.

Figure 2.8: Comparison of shares of 1.4-1.5L vehicles versus 1.5-1.6L vehicles for Chinese automakers and joint ventures



Note: Lines correspond to the market shares of engine size bands 1.4-1.5L versus 1.5-1.6L among vehicle trims offered by Chinese and joint venture manufacturers respectively.

To further investigate the problem quantitively, we use the following specification to compare the difference in responding to the tax rate change for Chinese and foreign automakers:

$$PM_y = \alpha + \beta post\_t_y + \varepsilon_y$$

Where,

PM_y is the share (engine size) for optimal engine size bins (including 1.4-1.5 litre, 1.9-2.0 litre, 2.4-2.5 litre and 2.9-3.0 litre) in year y for Chinese brands among all vehicles with engines between 1 litre and 3 litre, or in the second specification it is the share (engine size) for engine size bin M in year y for foreign brands among all vehicles with engines between 1 litre and 3 litre ;

$post\_t_y$ is the time trend variable measuring the time after the policy change, with 2007 as 1, 2008 as 2 and so on;

ε_y is an error term.

Table 2.14: Regressions comparing change in share of optimal engine sizes after model updates for Chinese and joint venture automakers

Optimal engine size shares	Chinese	Joint Venture
Constant term	.316** (.0316)	.252** (.0168)
Post t (in years)	.0265** (.00228)	.0113** (.00429)
R-Squared	.931	.408
N	13	13

Note:

1. *, ** and *** denote significance at the 5% 1% and 0.1% levels.
2. Standard errors are reported in parentheses.
3. The dependent variable in all columns is share of engine size bands right below tax cutoffs among vehicle trims offered, including 0.9-1L, 1.4-1.5L, 1.9-2L, 2.4-2.5L and 2.9-3L.

We can see that the coefficient for Chinese automakers is much bigger than the that of joint ventures (0.00265 compared with 0.0113). It again shows that Chinese automakers respond to the policy change by clustering right below the cutoff points much faster than the joint ventures, even though joint ventures started with an advantage in optimal engine size shares (31.6% compared with 25.2%).

7. Conclusion

This study shows that the engine size tax, which was designed partly to incentivize engine downsizing and fuel consumption reduction, might not have had its full intended effect. Even though the tax did help further reduce the engine size and thus reduce the fuel consumption rate, it also seems to have incentivized shifts towards turbocharging and supercharging, which have negative effects on fuel efficiency.

This study also shows that engine sizes have gradually clustered around cutoff points following the policy change. Furthermore, Chinese manufactures adjusted to the policy change faster than foreign manufacturers, redesigning their engines to the sizes right below the cutoff soon after the policy change. This might mean that the policy creates some kind of non-tariff barrier. On the other hand, this also provides insights on how a policy change in a major market could impact other markets.

With these observations, we suggest that if the Chinese government still choose to use engine size as a proxy for other variables including fuel consumption rate, it should instead consider using a continuous tax scheme instead. Different air intake technology should also be given special treatment for tax rate calculation to have better effects. In this way, the strategy of turbocharging to avoid paying taxes, which does not necessarily improve fuel efficiency, could be avoided. There would also be an incentive for automakers to slightly reduce engine size with each redesign.

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Appendix

The annually collected road tax or registration fee in China is called the vehicle and vessel tax. This tax is managed by provincial governments, and in all provinces, the rate is also based on engine size. Unlike the engine size tax, this tax rate is not multiplied with the price, but rather is a flat fee that varies across different engine sizes. The tax rate for different engine sizes in the direct-controlled municipality Beijing is listed below:

Table 2.10: Vehicle and Vessel Tax rate in Beijing as of 2017

Engine Size	**Tax rate (in CNY)**
>4 Litre	￥5280
3-4 Litre	￥3480
2.5-3 Litre	￥1920
2-2.5 Litre	￥900
1.5-2 Litre	￥480
1-1.5 Litre	￥420
<=1 Litre	￥300

Chapter 3: Impacts of Gasoline Price Changes on US and China Automobile Preference

1. Introduction

The elasticity of vehicle sales with respect to gas price has always been a key issue within the transportation field. While vehicle emissions and fuel consumption are affected by how much people drive, we may want to target fuel economy of the fleet rather than how much people drive, because it is easier to make technological changes rather than behavioral changes. It's in general difficult for people to reduce driving within several years. Therefore, this long-run fleet fuel economy has bigger impacts on GHG emission and energy consumption.

It is doubtful that consumers consider the full operational and fuel costs when buying cars (Greene 2010). If vehicle buyers fully incorporated the calculation of future fuel saving when making a purchasing decision, even without any government intervention that directly target vehicle purchasing, as long as operating externality is correctly adjusted with policy tool like a fuel tax, people would be motivated to make rational choices. If not so, then intervention for car purchasing like a feebate system or CAFE (Corporate Average Fuel Economy) standards are needed.

To study these questions, and make a contribution to the existing literature from both academic perspective and policy perspective, we collected monthly model-by-model vehicle sales data of 2008-2017 both from China and US, and link the data with concurrent gasoline prices and vehicle attributes such as fuel economy, size and power. Then we regress model-level vehicle sales data on gasoline prices and fuel economy to find out the impact of fuel price on the relative preference of vehicles with different fuel economy. We also use aggregated data to analyze impact of fuel price on different quartile by fuel economy as well. There is also a section looking into particular segments in both countries.

Results of these analysis all indicate that China and US automobile market have a major difference: while consumers in both countries prefer vehicles with higher fuel economy, fuel price changes don’t affect this preference in China as it does in the US. This also means that in China, fuel taxes might not be as effective as in United States to change vehicle purchasing behavior for long term benefits in fossil energy consumption and carbon emission reduction. Instead, other policies like feebates that directly affect purchasing price might be more effective tools to improve long term vehicle composition.

There is a large body of literature investigating how people value fuel economy when buying new cars (Helfand and Wolverton 2011). There are several reasons we may need more exploration of this problem.

First, existing studies reveal tremendous variation in estimates of the value fuel saving. Some show underestimation and some show overestimation or estimation that just reflects discounted future fuel saving. Could it be that this is related with cultural differences across different regions and different demographic groups? While a European study (Grigolon, Reynaert, & Verboven 2014) estimates higher elasticity than a US study (Train & Winston 2007), this may simply be due to the fundamental difference in purchasing behavior of vehicles in Europe and United States. There are also differences between mature and emerging markets, since consumers may lack experience in purchasing cars in new markets. Therefore, comparing vehicle preference changes in relation to gasoline price changes in different countries can be helpful to reveal these differences. This study for the first time compares US and China vehicle consumption behaviors with regard to fuel price changes and also make different policy recommendations.

Second, China has been the largest automobile market since 2009. If this trend continues, China will replace United States as the country with the largest automobile fleet and highest greenhouse gas emissions from transportation in the near future. However, there are relatively few studies that investigate how the automobile market in China reacted to changes in fuel prices.

Lastly, the world automobile market also has gone through major changes in the past 10 years. There has been a noticeable increase in the market share of SUVs. In some markets, such as United States, it has even exceeded the share of passenger cars. Previous studies usually focus on different segments of passenger cars but this study contributes to the body of literature by including SUVs in the analysis.

This paper consists of seven sections. Section 2 reviews the literature on fuel cost and vehicle consumption. Section 3 presents a model on how fuel costs affect consumer decisions. Section 4 describes and summarizes the data used for this study. Section 5 presents and compare results from regressions on sales with regards to fuel price for US and China. Section 6 discuss the possible causes for the US and China vehicle consumption behavior differences and their policy implications. Section 7 is conclusion.

2. Literature Review

There are many studies on purchasing behaviors within the automobile market due to its important effect on energy consumption and GHG emissions. Most of these studies approach the problem by estimating how much consumers value fuel economy. Researchers have long debated whether consumers could reasonably approximate the real discounted present values of future fuel costs when making vehicle choices. As Greene's (2007) literature review shows, many works have indicated possible inefficiency of the energy market caused by consumers' undervaluing of energy saving, and five types of market failures have been identified (ACEEE, 2007): principal agent conflicts, information asymmetry, transaction costs, bounded rationality and external costs and benefits.

The principle agent conflicts are conflicts where an agent's incentives don't align with those of the principle. These conflicts arise because the energy efficiency of vehicles is determined by automakers, not consumers. Even if some consumers are willing to purchase the most efficient vehicles utilizing the most advanced hybrid technology, these vehicles might not be offered by vehicle manufacturers, as automakers might want to slowly improve the efficiency over generations so that it can keep improving. In another case, vehicles are purchased by rental companies whose major concern are the low purchase costs, but fuel costs are paid by rental customers not rental companies so that the purchase decisions are mostly made according to other vehicle attributes, not energy efficiency.

Information asymmetry exists as consumers may not fully know the energy efficiency of a vehicle, particularly before the purchase is made. Most consumers only learn about the efficiency of a vehicle model through official ratings like the EPA (Environmental Protection Agency) MPG (miles per gallon) rating, which are measured through test cycles. However, the fuel efficiency that consumers experience might be significantly different with the EPA test cycles, but they would be unable to know this difference without experience. In some cases, automakers might tune the vehicle to specifically perform well with the official test, or even cheat the test like the Volkswagen scandal, in these cases consumers could not know the real efficiency through fuel economy ratings.

Transaction costs compromise energy savings in cases where the owner of a vehicle is willing to replace their vehicle with a vehicle with better efficiency if she or he needs to drive much more, but she or he would have to bear the loss from the purchase transaction which is much higher than the fuel savings, so the replacement have to be delayed.

Bounded rationality describes a common situation that the consumers only have limited knowledge and expertise when making choice on vehicle purchasing regarding long-term fuel costs. Consumers might not be able to accurately calculate the full life cycle costs of operating different vehicles, and might not have the time to do enough research. In this case they only make “satisficing” (satisfying but less than optimal) choices.

In addition to these market failures that make it difficult for consumers to make optimal choice with regard to internal fuel costs, vehicle energy efficiency also involves external costs and benefits.

Some of the costs or benefits related with fuel efficiency, such as greenhouse gas efficiency, energy security and air pollution, are mostly burdened on other people in the society. When purchasing decisions are made, these external costs and benefits are often ignored. It is helpful to quantify these market failures’ impact on consumer choice. However, studies differ on how much (or whether or not) consumers undervalue fuel savings.

Among the nine studies mentioned below, three studies (Berry et al, Train et al and Allcott et al) found that consumers are indifferent towards fuel economy difference in vehicles. Three different studies (Espey et al, Langer et al and Busse et al) found that consumers do internalize future fuel savings as reflected in the higher purchasing price they are willing to pay. Two studies (Li et al and Klier et al) found that consumers are affected by future costs, however, the impact are modest, as the calculated discount rate would be very large. One found this discount rate has been changing over time, therefore the impacts of fuel price were also different in different periods.

Berry, Levinsohn and Pakes (1995) developed a method for estimating both demand functions with random coefficients and cost functions, based on aggregate sales data for over 2,000 models of vehicles over the period 1971-1990. In their study, the average value of fuel economy (MPG) is found to be not significantly different from zero, meaning that consumers in general are indifferent towards fuel economy. This paper provides a methodology that form the basis of many following studies.

Train and Winston (2007) used a mixed logit model to analyze the declining market share of domestic automakers in the U.S., based on a random sample of consumers who purchased a 2000 model year vehicle. Their model allows the estimation of average values, values that vary systematically with consumer attributes, and values that are randomly distributed in the population. They found that the effect of fuel consumption (gallons per mile) in the average utility equation, was negative as expected but not statistically significant.

The above two studies do not directly estimate how gasoline price changes affect market share of different vehicles, or how would future fuel savings could be translated to difference in selling price. Instead, these studies only give qualitatively estimation of whether fuel economy affect the vehicle's utility for consumers.

Allcott and Wozny (2014) tested whether the effect of a $1 change in the price of a vehicle is the same as the effect of a $1 change in the discounted present value of fuel costs. They used a nested logit discrete choice model based on a data set of both new and used vehicles up to 25 years old in use in the United States between 1999 and 2008. They also found that consumers substantially undervalue future fuel costs in their choices of new and used vehicles, as consumers count a present value dollar of fuel costs as only $0.25 relative to a dollar of purchase price, with a discount rate of 15% for future fuel cost.

Espey and Nair (2005) use a hedonic regression model to estimate the consumers' willingness to pay for different vehicle attributes in 2001. The vehicle attributes, including fuel consumption (gallons per mile), size, power, performance, safety, comfort, reliability and whether or not the vehicle is classified as a luxury vehicle, were obtained from Consumer Reports and Ward's Automotive Report web sites. They found that automobile buyers actually fully internalize fuel cost savings attributable to improved fuel economy at a discount rate of 1% for future fuel cost.

Langer, A. and Miller (2008) measured the extent to which the prices of new light-duty vehicles responded to changes in the price of gasoline, based on 300,000 observations of weekly automobile price data from 2003 to 2006. Instead of directly using the suggested retail price, they included incentives provided by manufactures and dealers to obtain more accurate transaction prices. They found that automobile manufacturers would adjust retail prices as much as 15-18 percent of change in future fuel cost when gasoline price changes.

The above three studies all assessed people willingness to pay for future fuel economy. Their results show whether consumers fully internalize fuel savings through purchasing price, yet they did not directly investigate how fuel price affects the market share of vehicles being sold.

Busse, Knittel and Zettelmeyer(2012) estimated the effects of changes in gasoline prices on the market shares and prices of new and used automobiles, based on a sampled actual vehicle transactions data from September 1, 1999 to June 30, 2008. They estimated multiple models and found that both vehicle prices and market shares respond to gasoline prices. The implicit discount rates for future fuel cost are similar with interest rates paid by car buyers who borrow, showing little evidence for consumer myopia. Their study in particular provide the basis for the aggregate analysis used in our study.

Li, Timmins and von Haefen (2009) examined the effects of gasoline prices on the automotive fleet's composition, using the vehicle registration data in 20 U.S. metropolitan statistical areas. They found that high gasoline prices affect fleet fuel economy through two channels: changing the distribution of new vehicle purchases, and speeding the scrappage of older, less fuel-efficient used vehicles. They found that gasoline prices have statistically significant effects on both channels, but that their combined effect results in only modest impacts on fleet fuel economy. ("10 percent increase in gasoline prices from 2005 levels will generate a 0.22 percent increase in feet fuel economy in the short run and a 2.04 percent increase in the long run")

Klier and Linn (2010) analyzed the effects of fuel price changes on vehicle sales based on aggregate detailed model and model year sales data from 1970 to 2007. They do not directly estimate a measure of willingness to pay, but instead focus on the effect of fuel economy on sales of different vehicle models and the impact of the market share changes on average fuel economy. They found that the price of gasoline to have a significant effect on vehicle model sales. The gasoline price increase from 2002 to 2007 explained nearly half of the decline in market share of

US manufacturers and large SUVs. However, an increase in the gasoline tax only modestly raises average fuel economy.

Leard, Linn, and McConnell (2016) estimated the effect of changes in gasoline prices on the average fuel economy of newly sold automobiles, based on monthly data from 1996 to 2015. They found that fuel prices had a smaller effect on market shares in recent years than previously, which appeared to be driven by a stronger response to rising than falling or stable prices.

The last four studies directly investigate the impacts of fuel prices on market distribution among different vehicles, or sales-weighted average fuel economy, which are most closely correlated with the scope of this study. Different from these four studies that all focus in US only, this study compares the impact of fuel prices across US and China.

In contrast to the rich literature studying the impacts of gasoline prices on consumption of automobiles of different fuel economy, few publications that specifically investigates impacts of gasoline price changes on Chinese automobile market at the model level. There are a couple of studies that investigate Chinese automobile consumption characteristics in general.

Hu et al (2012) used survey data to analyze preference of Chinese automobile consumers in regard to functional image congruity and symbolic image congruity. They found that even though symbolic image congruity has positive impact on consumer preference in the US, its impact is negative in China when a brand's perceived symbolic image is higher than consumers' idea expectations. They also found that brand familiarity does not moderate the role of symbolic image congruity in Chinese consumers' brand preference.

Chen et al (2016) built a random coefficients model to estimate impacts of different vehicle parameters and characteristics on vehicle sales. They found that vehicle length, weight, seating capacity and horsepower all have positive impacts on sales of a vehicle model.

Even though there haven't been studies that directly monetize Chinese consumers valuation of fuel economy or whether fuel price changes affect consumers' preference of vehicles, other developing countries have been studied for this matter. Chugh et al (2011) used hedonic price regression for four different segments to compute the marginal corresponding price increase for an increase in fuel economy. They thus concluded that the Indian consumers do internalize future fuel savings when purchasing vehicle.

There also have been studies that investigates impacts of gasoline price across countries. Burke and Nishitateno (2012) used gasoline price and vehicle market data from 132 countries and found that higher gasoline prices motivate consumers to choose more fuel-efficient vehicles. However, they estimate coefficients for the 132 countries altogether, not allowing unique coefficients for each country. Our study instead will investigate US and China separately and compare the results thereafter.

3. Theoretical Framework

This study focuses on the impacts of the fuel price on the sales of different vehicle models. Before we come to the estimated specifications used in this study, we could first look at how consumers choose from different vehicle models and why the choices are affected by fuel price changes.

In general, when a consumer is faced with the choice from different vehicle models, the consumer compares characteristics of different vehicle models. The fuel cost is one of the largest costs of operating a vehicle. When fuel price changes, the fuel cost also changes. Differences in fuel cost between vehicles are smaller when fuel are cheaper, and become larger when fuel are more expensive. Therefore, every consumer is more likely to purchase vehicles of better fuel economy when gasoline prices are higher and their market share could possibly rise along with gasoline price.

To better understand the relationship between fuel price and consumer preference, we first examine the utility of a vehicle to a consumer. Assuming the market only contains two vehicle models, one with higher fuel consumption rate (vehicle H) and one with lower fuel consumption rate (vehicle L), their utility for consumer i could be represented in the two following equations:

$$u_{iH} = \alpha_H + \beta FCR_H + \gamma \sum_t \frac{1}{\delta^{it}} \cdot P_t^{gasoline} \cdot FCR_H \cdot VMT^{it} + \varepsilon_{Hi} \quad (1)$$

$$u_{iL} = \alpha_L + \beta FCR_L + \gamma \sum_t \frac{1}{\delta^{it}} \cdot P_t^{gasoline} \cdot FCR_L \cdot VMT^{it} + \varepsilon_{Li} \quad (2)$$

Where,

- The terms $\alpha_H + \beta FCR_H$ captures performance for vehicle attributes:
    - α_H and α_L are dummy variables that capture the utility of vehicle attributes unrelated to fuel consumption.
    - FCR_H and FCR_L are fuel consumption rates (L/100km) for vehicle models with high and low fuel consumption rate respectively.
- The term $\gamma \sum_t \frac{1}{\delta^{it}} \cdot P_t^{gasoline} \cdot FCR_H \cdot VMT^{it}$ captures expected future fuel costs:
    - δ^{it} is the discount rate at time t for person i and reflects time preferences. It reflects how E(fuel cost) enters in utility. If δ^{it} is close to 1, consumer i is forward looking. If δ^{it} is far less than 1, consumer i is myopic.

    - $P_{gasoline}^{t}$ is the gasoline price at time t. The consumers, needs to make assumptions about expectations of future fuel costs. Generally, consumer use today’s fuel price as the best guess of the future gasoline price (Anderson et al 2013).
    - VMT^{it} represents the miles driven by consumer i using this vehicle in time t after purchasing the vehicle.
- ε_{Hi} and ε_{Li} are the unobserved characteristics of vehicle H and L that are randomly distributed across the population.

One should note that γ should be negative since future fuel cost is negative utility. In a multinomial logistic regression, with ε_i as independent and identically distributed extreme values (Train 2003), if we use θ_H to represent the observed part of utility of vehicle H: $\theta_H = \alpha_H + \beta FCR_H + \gamma \sum_t \frac{1}{\delta^{it}} \cdot P_{gasoline}^{t} \cdot FCR_H \cdot VMT_t$ and let $\theta_L = \alpha_L + \beta FCR_L + \gamma \sum_t \frac{1}{\delta^{it}} \cdot P_t^{gasoline} \cdot FCR_L \cdot VMT_t$, then the probability of consumers choosing vehicle model H over model L is:

$$P(u_H > u_L) = \frac{e^{\theta_H}}{e^{\theta_H}+e^{\theta_L}} = \frac{e^{\alpha_H+\beta FCR_H+\gamma\sum_t \frac{1}{\delta^{it}}\cdot P_{gasoline}^{t}\cdot FCR_H\cdot VMT^{it}}}{e^{\alpha_H+\beta FCR_H+\gamma\sum_t \frac{1}{\delta^{it}}\cdot P_{gasoline}^{t}\cdot FCR_H\cdot VMT^{it}}+e^{\alpha_L+\beta FCR_L+\gamma\sum_t \frac{1}{\delta^{it}}\cdot P_{gasoline}^{t}\cdot FCR_L\cdot VMT^{it}}} \quad (3)$$

We derive the derivatives of $P(u_H > u_L)$ over fuel price:

$$\frac{dP(u_H>u_L)}{dP_{gasoline}^{t}} = \frac{{e^{\theta_H}}'(e^{\theta_H}+e^{\theta_L})-e^{\theta_H}(e^{\theta_H}+e^{\theta_L})'}{(e^{\theta_H}+e^{\theta_L})^2} = \frac{e^{\theta_H}e^{\theta_L}({\theta_H}'-{\theta_L}')}{(e^{\theta_H}+e^{\theta_L})^2} = \frac{e^{\theta_H}e^{\theta_L}\gamma\sum_t \frac{1}{\delta^{it}}\cdot VMT^{it}(FCR_H-FCR_L)}{(e^{\theta_H}+e^{\theta_L})^2} \quad (4)$$

Equation (4) is always negative since γ is negative and all the other terms including $(FCR_H - FCR_L)$ are positive. Therefore, our analytical model shows that gasoline price increases would always lead to lower probability of consumers choosing a vehicle model with a higher fuel consumption rate, all else equal. Based on equation (4), we also learn how other factors affect the impacts of gasoline prices:

- If the discount rate δ_{it} decreases, $\frac{dP(u_H>u_L)}{dP^t_{gasoline}}$ will increase. This means that if the same future fuel savings would translate to higher utility for consumers now, gasoline prices would be more important and have a bigger impact on consumers' choice of vehicles.
- Similarly, if vehicles are driven more by consumers, gasoline price changes would also have a bigger impact on consumers' choices of vehicles, or market share of vehicles. When VMT^{it} increases, $\frac{dP(u_H>u_L)}{dP^t_{gasoline}}$ also increases, which means that the advantage of vehicle H's utility to consumers over vehicle L's utility is enlarged and market share of vehicle H, the more efficient vehicle, rises.Therefore, higher VMT increase total fuel consumption and thus increase fuel cost and potential future fuel savings.

4. Data

This section first states the source of the data, and then provides summary statistics and figures that help describe the gasoline price and vehicle market trends. In summary, both the US and Chinese auto market have been changing over the past decade. However, the Chinese auto market has experienced more rapid changes in the last few years. The Chinese vehicle market is also more concentrated in certain segments: vehicles sold in China are cheaper, smaller, less powerful, and more fuel efficient than in US. The differences between these two markets and reasons for these differences are also discussed in this section.

The analysis uses vehicle specification and sales datasets including data on vehicle dimensions, weight, fuel efficiency rating, engine horsepower and engine size, merged with vehicle model sales and gasoline prices. The Chinese dataset includes records from 2008 to 2017, while the US dataset only includes records from 2012 to 2017. The Chinese vehicle specification data is scraped from "Autohome"[38] (the biggest online vehicle database in China) and contains specification data for all vehicle models and trims. The vehicle sales data was published by China Passenger Car Association. The US vehicle specification data and sales data is provided by Ward's Auto.

The US gasoline price we used is published by[39]. For China, since national average gasoline price data is not accessible, regional price differences are small, and price changes are regulated by the national government, we used the Beijing historical gasoline price trend to represent the overall price of gasoline in China[40]. As we can see from the following graph, gasoline prices in both countries first rose in the 2008-2013 period, and then declined from 2014 to 2016 before rising again from 2016 to 2017.

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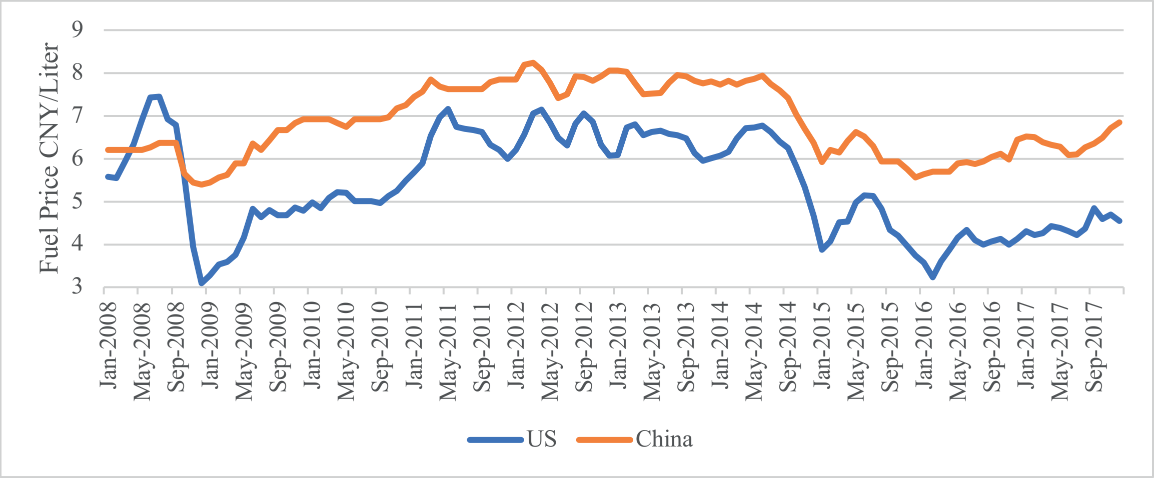
[38] Website URL: https://car.autohome.com.cn/

[39] Weekly Retail Gasoline and Diesel Prices. U.S. Energy Information Administration https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_w.htm. Retrieved 12/01/2018

[40] Data Center eastmoney.com, http://data.eastmoney.com/OilPrice/oil_city.aspx?city=beijing, Retrieved 12/01/2018

Figure 3.1: Gasoline price changes in US and China 2008-2017



Note: Lines correspond to the average price for regular, unleaded gasoline in CNY / liter in the U.S. and China.

Source: U.S. Energy Information Administration and eastmoney.com

The following table summarizes the sales-weighted attributes of the two countries for same period from 2012 to 2017.

Table 3.1: Comparing sales-weighted attributes of automobile sold in US and China

	US		China	
	Mean	SD	Mean	SD
MSRP (US dollars)	26816	9673	17670	10835
Fuel Consumption Rate (L/100km)	9.5	4.2	6.9	1.0
Power (kw)	161	56	94	23
Engine Displacement (cc)	2779	923	1611	290
Length (mm)	4833	377	4523	270
Width (mm)	1875	95	1779	68
Height (mm)	1634	177	1558	112
Weight (kg)	1645	331	1334	208

Note: SD stands for standard deviation. MSRP stands for manufacturer's suggested retail price

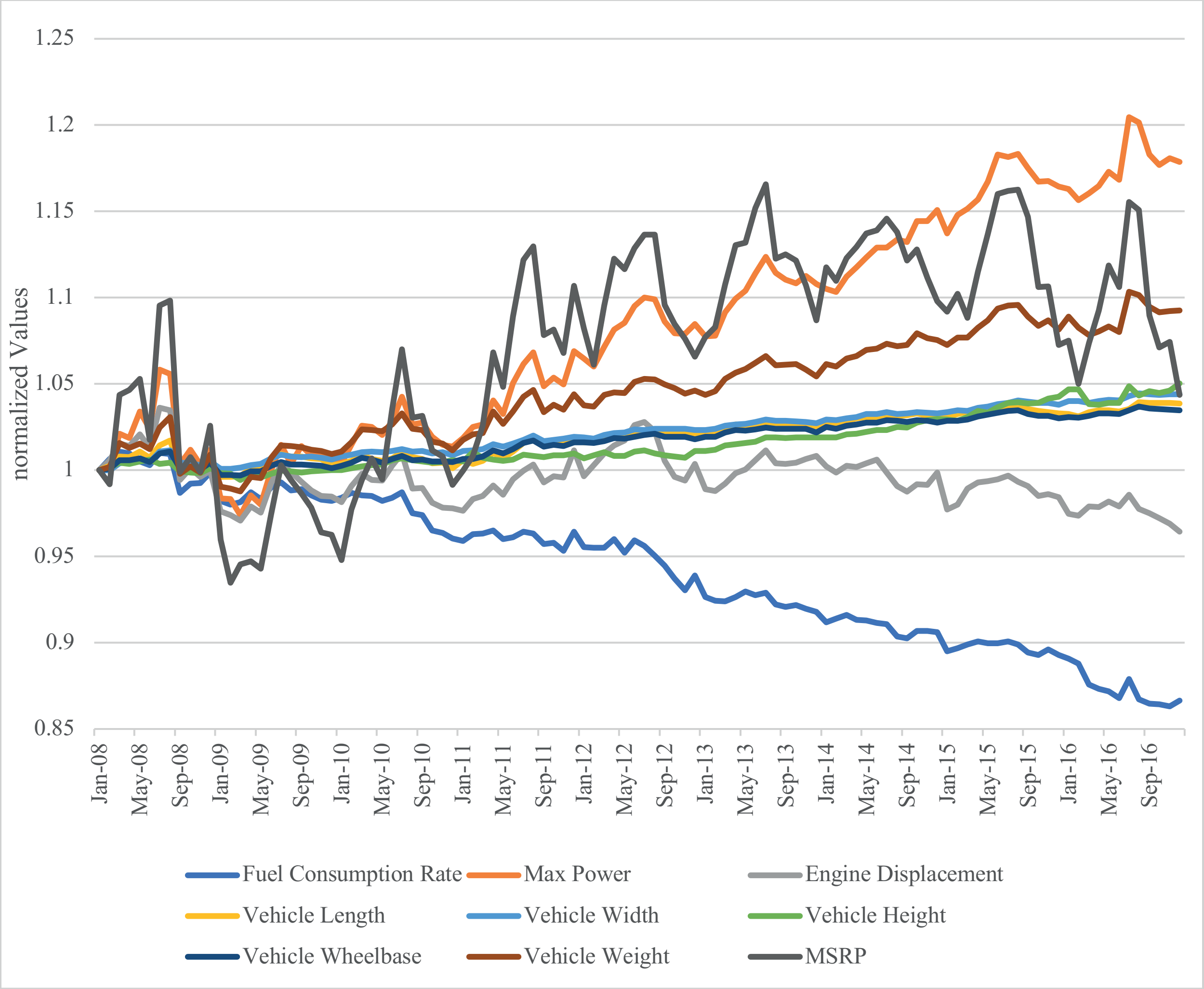
As the table shows, the two markets are quite different in many ways. The average automobile sold in US is about twice as expensive, twice as powerful, consumers more than 70% more fuel, and more than 20% heavier. The average vehicle sold in the states are also much bigger than in China. The fuel consumption rate, however, is not directly comparable, since the US official fuel economy rating is based on the EPA cycle, which involves much more frequent and irregular speed changes and is much more realistic than the NEDC test cycle that Chinese official fuel consumption rate rating is based on. The NEDC test cycle often yields fuel consumption rate that is 65-75% of EPA test cycle fuel consumption rate, therefore it is safe to assume that the US has higher fuel consumption rates in general.

The Chinese vehicle market has been rapidly evolving in the following ways:

- Average vehicle weight and vehicle sizes have been rising constantly over the past 10 years, despite the downturn in 2009 due to adding micro vans. This is consistence with the rise in average vehicle prices, indicating the Chinese consumers are buying bigger and more expensive vehicles. Specifically, vehicle heights have been increasing quickly beginning 2012, which indicates a trend of SUVs becoming more popular.
- Average prices of vehicles sold are higher in the middle of the year and lower towards the end of year. This is possibly related with the fact that consumers in rural areas and consumers with lower income tend to buy vehicles before the Chinese New Year.
- Average vehicle power and weight has been increasing in the past 10 years, despite the downturn in 2009 due to the addition micro vans. At the same time, the average fuel consumption rate has been decreasing. This corresponds to an advancement of vehicle technology in China.
- Average engine displacement has been fluctuating around same level before 2012. Since 2012, it has been consistently decreasing, possibly as a delayed response to higher tax on engine size in 2008 and 2010.

The following figure is the summary of the weighted average values of major vehicle attributes in China, with values indexed to their respective values in January of 2008:

Figure 3.2: Sales-weighted average values of vehicle attributes in China 2008-2017



Note: Lines correspond to the sales-weighted average values for different vehicle attributes in China. With values in January 2008 normalized to 1.

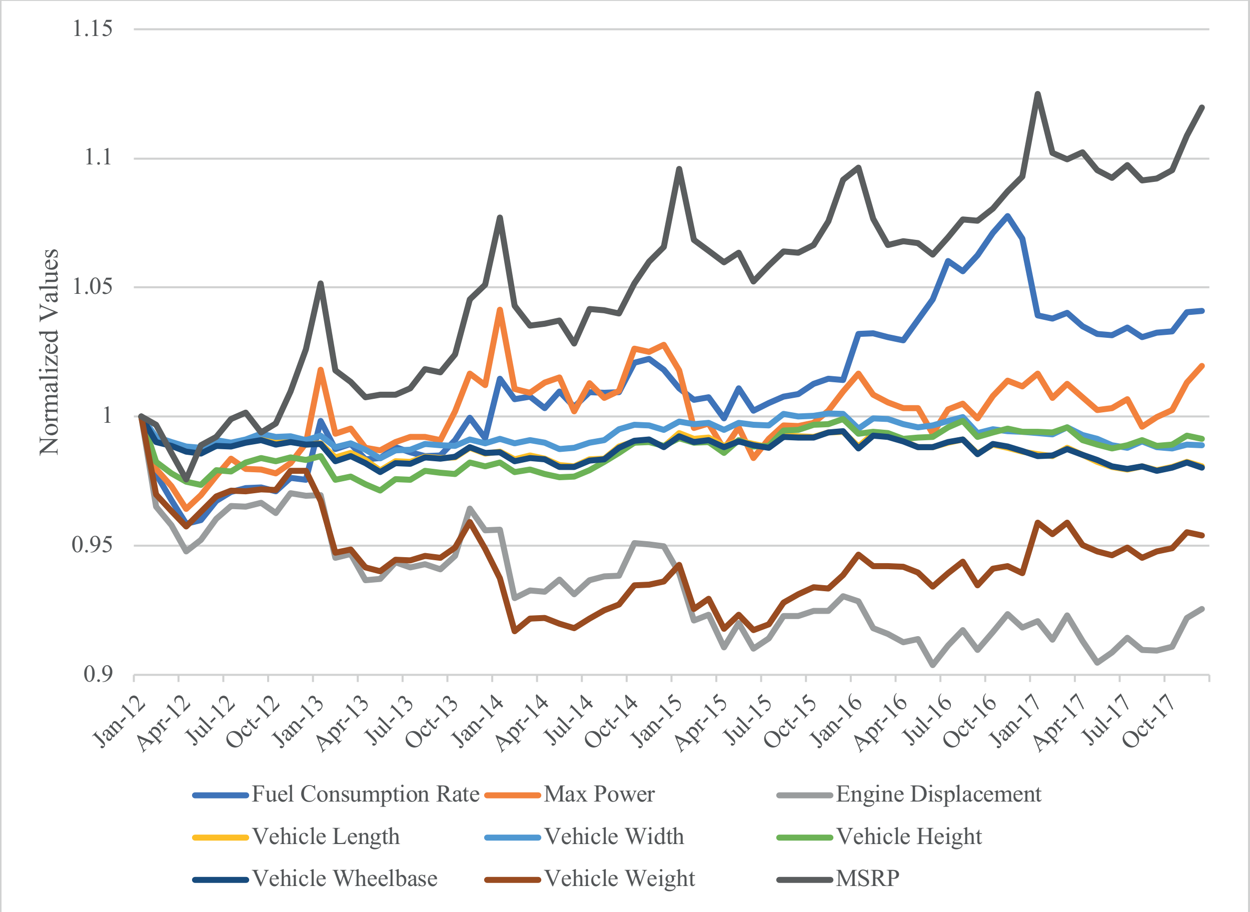
The US auto market differs in many respects:

- Average vehicle weights were decreasing prior to 2014 but began growing again afterwards. Average fuel consumption rate, on the other hand, was decreasing prior to 2013 and increasing afterwards. This corresponds to the peak in gasoline prices in 2013 to 2014. Even though the US has fuel economy regulations (CAFE), the standards are easier to comply for bigger vehicles, such as SUVs and trucks. Therefore, this downturn is not unexpected because lower gasoline prices correspond to a trend towards larger vehicles.

- Another major difference of the US market is the seasonality. Different with China, in US the vehicles sold in winter tend to be larger, more powerful and more expensive. This might be related with better deals for vehicles in the winter season in order to clear the lots for new model year vehicles. These trends indicate that seasonal fixed effects are necessary in our regressions.

The following is the summary of the weighted average values of major vehicle attributes in US, with values indexed to January of 2012:

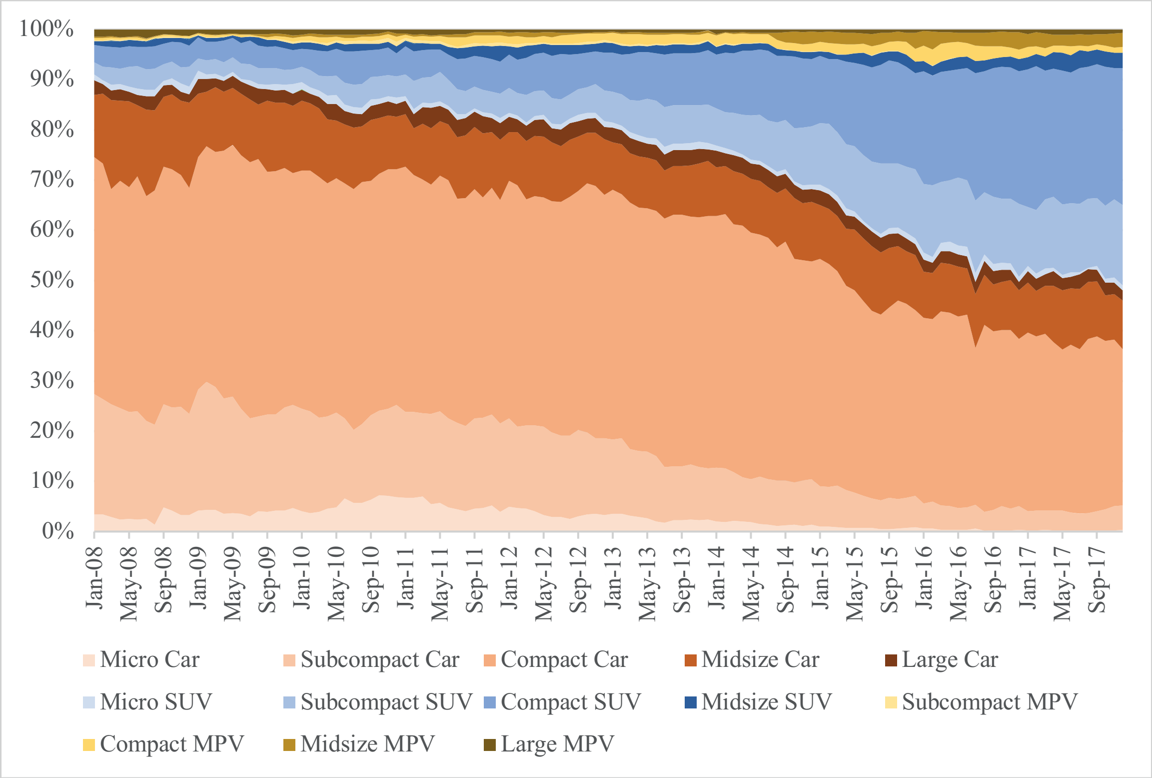
Figure 3.3: Sales-weighted average values of vehicle attributes in US 2012-2017



Note: Lines correspond to the sales-weighted average values for different vehicle attributes in US.

With values in January 2012 normalized to 1.

Figure 3.4: Market share of different segments of China 2008-2017



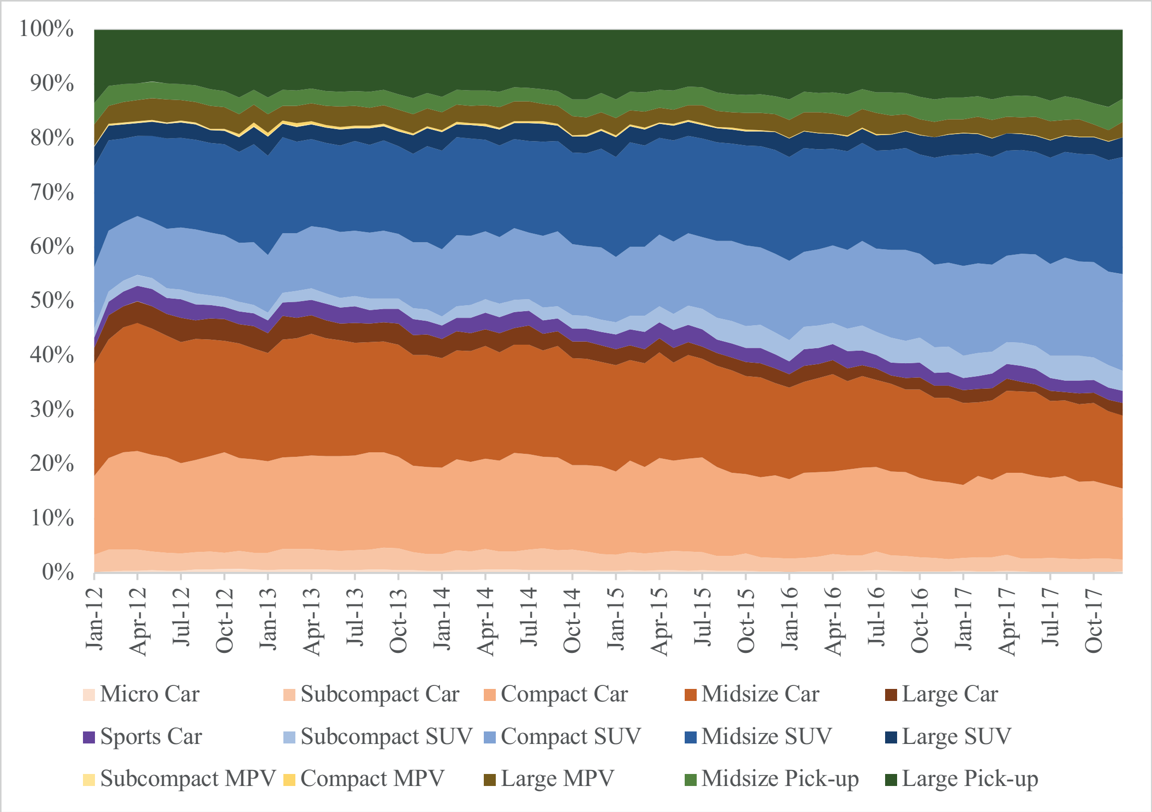
Note: Heights correspond to the market share for different vehicle segment in China.

As we can see from the above graph, the Chinese auto market has been rapidly changing over the last decade. In 2008, cars (mostly sedans) still dominated the Chinese vehicle market (market share close to 90%). However, since 2009, the market share of SUV (sport utility vehicles) had been rapidly increasing. By the end of 2017, the share of SUV had risen to match the share of passenger cars, each accounting for about 50% of the entire market.

If we look at specific segments, we can see that until mid-2014, compact car was the most dominant segment in Chinese marking, accounting for nearly 50% of the entire market. However, since mid-2014, its share has decreased to just above 30%. Although compact cars are still the largest segment by market share, the share of compact SUVs had been rising to about 27%. The second and third largest segments in 2008 were subcompact cars and midsize cars. In 2017 compact and subcompact SUVs replaced these segments as the “big three”. More generally, Chinese automobile market has greatly diversified. The market share of MPVs (multi-purpose vehicles, or minivans) also rose significantly.

Vehicle sizes sold also increased. In 2008, subcompact cars accounted for a quarter of Chinese vehicle market. In 2017 it merely accounted for less than 5% of the market. Micro cars, which were the backbones in first wave of automobile penetration in China in the early 2000s, almost disappeared from Chinese market in the past 10 years. Meanwhile, the total market share of bigger vehicles, mainly midsize cars and compact SUVs, had risen from 17% to 45%.

Figure 3.5: Market share of different segments of US 2012-2017



Note: Height correspond to the market share for different vehicle segment in US.

The automobile market in the US has been much more stable. Similar with China, the US market also experienced a shift from cars to SUVs in the past. However, the transition started much earlier: in 2012 SUVs already accounted for more than one-third of the market. This trend continues from 2012 through 2017, though at a much slower rate. The market share of SUVs only increased from 35% to 47% in US, while in China it increased to 47%, which is more than triple of the 14% share at the beginning of 2012.

We also observe that in 2014, when gasoline prices experienced a downturn from its historical peak, there was a corresponding transition from cars to SUVs. The shift is mainly from midsize cars to compact SUVs, as they are actually similarly in size (compact SUVs are shorter than midsize cars, but they are also taller and have bigger trunk room) and price.

The US automobile market is also more diverse: no segment ever accounted for more than 25% of the entire market. Compact cars, midsize cars, compact SUVs, midsize SUVs and large pick-up trucks all take up a significant share in the US market. Vehicles that are not family-friendly, like sports cars, are also more popular in US. Pick-up trucks also sold much more in US than in China (they are classified as commercial vehicles in China and are indeed very rarely bought for family use).

Even though vehicles in China increased in size on average, US consumers still buy bigger vehicles on average, like midsize and large SUVs, large minivans and pickup trucks.

5. Empirical Models and Results

5.1 Analysis of change in sales of individual vehicle models

The first part of this study examines the sales change of each vehicle models when gasoline prices fluctuate. As discussed in the previous section, we expect consumers to be more likely to purchase vehicles with better fuel economy when gasoline prices are higher. Therefore, sales of more efficient vehicle models increase alongside gasoline price increases.

We employ an econometric approach using a linear regression with a model specification as follows:

$$q_{jt} = \alpha + \beta FCR_{jt} + \gamma FCR_{jt} \cdot P^{t}_{gasoline} + \sum_{a} \delta_a Y_{ajt} + \varepsilon_{jt}$$

Where,

- q_{jt} indicates the total sales of vehicle model j in month t in China or US. Market share could also be used instead here.
- FCR_{jt} indicates the fuel consumption rate (L/100km) of the vehicle model j in month t.
- $P_{gasoline}^{t}$ indicates the gasoline price in month t ($/gal). As discussed in the previous section, we implicitly assume that consumers use the price of gasoline at the time of purchasing the vehicle to predict future gasoline prices.
- Y_{ajt} are a set of other vehicle attributes a, which include MSRP (manufacturer's suggested retail price [$]), maximum engine power (kilowatts), vehicle weight (kilograms), and vehicle floor area (measured by vehicle length multiplied by width [meters]). δ_a are corresponding coefficients that measure the elasticity of each vehicle attribute to vehicle sales.
- ε_{jt} is an error term.
- Vehicle sales, price, vehicle attributes and interaction term for fuel prices are all logged.

Because fuel prices fluctuate independently, with both vehicle fuel consumption rate and its interaction with fuel price in the specification, we are able to isolate the effects of fuel cost from the effects of fuel consumption rate.

As discussed in section 3, higher fuel price would lead to bigger advantage for more efficient vehicles and thus increase its sales. If β and γ are both negative, it means consumers generally prefer vehicles with lower fuel consumption rate all else equal. However, higher fuel prices further decrease the sales of vehicles with higher fuel consumption rate through the interaction term.

The following table shows the result of regressions on the logarithm of sales. Body style fixed effects are also included in some specifications. The interaction term of fuel consumption rate and fuel price are represented as fuel costs here.

Table 3.2: Regression results analyzing impacts of fuel cost and other attribute on vehicle model sales in US and China (the standard errors are in the parentheses, same below)

Log Sale	(1)		(2)		(3)		(4)	
Fixed Effects					Brand		Month of Year	
	US	China	US	China	US	China	US	China
Log MSRP	-2.591***	.451***	-2.603***	.421***	-2.603***	-1.858***	-2.867***	.425***
	(.037)	(.034)	(.037)	(.035)	(.048)	(.060)	(.037)	(.035)
Log Power	.766***	-.285***	.761***	-.224*	.759***	1.182***	.936***	-.228**
	(.057)	(.086)	(.057)	(.087)	(.056)	(.093)	(.057)	(.087)
Log Weight	1.161***	-3.076***	1.175***	-3.033***	1.176***	-.675***	.669***	-3.040***
	(.133)	(.114)	(.133)	(.114)	(.134)	(.126)	(.133)	(.114)
Log Floor Area	4.184***	4.748***	4.132***	4.753***	4.120***	4.613***	4.117**	4.745***
	(.200)	(.190)	(.200)	(.191)	(.210)	(.188)	(.200)	(.190)
Log FCR	-1.406***	-1.587***	-1.166***	-2.116***	-1.122***	-1.576***	-1.221***	-2.116***
	(.074)	(.064)	(.097)	(.120)	(.092)	(.111)	(.096)	(.120)
Log Fuel Cost			-.197***	.465***	-.231***	.367***	-.159***	.475***
			(.051)	(.092)	(.04)	(.083)	(.052)	(.092)
Constant Term	-13.35***	23.08***	-12.18***	21.78***	-3.735***	3.254***	-4.002***	21.82***
	(.672)	(.594)	(.675)	(.638)	(.682)	(.765)	(.674)	(.637)
N	16888	28968	16888	28968	16888	28968	16888	28968
R-Square	.3448	.0706	.3454	.0713	.3405	.0053	.3454	.0713

Note:

1. *, ** and *** denote significance at the 5% 1% and 0.1% levels.
2. Standard errors are reported in parentheses.

3. The dependent variable in all columns is the log of sales at the model, month level. Columns (3) and (4) include brand and month of year fixed effects respectively.
4. Study period for the US and China are 2012 - 2017 and 2008-2017, respectively

First, we can briefly look at how other vehicle attributes are correlated with vehicle model sales based on the regression results. List prices (MSRP) are negatively correlated with market performance in the US, whether or not brand fixed effects are included. However, in China, list prices are only negatively correlated with vehicle sales when brand fixed effects are included. Otherwise, vehicles that are priced higher are generally more popular. This indicates that Chinese consumers care more about brand image, which represent more expensive vehicles on average.

Similarly, engine power is positively correlated with market performance in the US in both models with and without fixed effects controls for body style. However, in China, engine power is only positively correlated with vehicle sales when brand fixed effects are included. This indicates that for a given brand, Chinese consumers prefer higher power but are generally willing to purchase a vehicle model from a better brand by sacrificing engine power. Vehicle weights are negatively correlated with market performance in China across all four specifications. In US, however, the correlation is positive. In both countries, vehicles that have a larger area (vehicles that are longer or wider) are more popular in the market.

We next discuss the difference in impact of gasoline price changes in the two countries. The results reveal that when fuel consumption rates are included in the specification while the interaction with fuel price are excluded, the estimated coefficients in both countries for fuel consumption rates are negative. This probably indicates that consumers in both countries value fuel efficiency of vehicles on average. However, when the interaction term with fuel price is also included, the results for two countries are quite different. In US, coefficients of fuel consumption rate and the interaction term are both negative. This is consistent with our hypothesis, that an increase in gasoline price would lead to higher market share for more efficient vehicles, as sales of vehicles with lower consumption rate decrease less than vehicles with higher consumption rate.

In China, however, when coefficients of the interaction term are positive, after the interaction term is added to the specification. The coefficients of the fuel consumption rates still remain negative. It is difficult to explain why an increase in fuel price in China would lead market share of more efficient vehicles to actually decrease. We have to admit that some unobserved variable might be coincidentally correlated with gasoline price changes, yet are also correlated with vehicle sales. For example, maybe the rise of gasoline price from 2008 to 2014 coincides with the rapid rise of income of Chinese car buyers and thus people became less concerned about fuel efficiency. Without better data on the socio-economic data of the vehicle buyers in China, we could not draw any conclusion. This might be material for future research.

That being said, the results show that it is highly unlikely that increase in gasoline prices would motivate Chinese consumers to buy efficient vehicles more like in the US.

5.2 Aggregate analysis

The second part of this study builds upon the Busse et al (2012) study. Impacts of gasoline prices are studied at the aggregate level, with vehicle models are divided into quartiles based on their fuel consumption rate ranking.

$$Q_{kt} = \alpha + \beta P_{gasoline}^{t} \cdot \text{FCR Quartile}_{k} + \gamma \text{MPG Quartile}_{k} + \tau_t + \varepsilon_{kt}$$

Where,

- $P_{gasoline}^{t}$ indicates the gasoline price in month t ($/gal).
- FCR Quartile_{k} indicates which fuel consumption rate quartile the vehicle model belongs.
- τ_t is the fixed effect of month t.
- ε_{kt} is the error term.

If our hypothesis that an increase in gasoline prices would decrease the relative attractiveness of less efficient vehicles, we should observe an increase in sales of quartiles with lower fuel consumption rates.

To test the hypothesis that higher fuel prices do not contribute to higher sales of more efficient vehicles in Chinese market, we used the Busse et al (2012) study to analyze how market share of different quartiles ranked by fuel consumption rate. Results are shown in the following table, the 1st Quartile is the quartile with worst fuel economy and the 4th Quartile is the quartile with best fuel economy.

Table 3.5: Regression results analyzing impacts of fuel cost on market share of different fuel efficiency quartiles in US and China

Market Share	US	China
1st Quartile	.334**	.151***
	(.0285)	(.0188)
2nd Quartile	.102***	.340***
	(.0285)	(.0188)
3rd Quartile	.291***	.185
	(.0285)	(.0188)
4th Quartile	.173***	.324***
	(.0285)	(.0188)
1st Quartile · Fuel Price	-.0401***	-.0198
	(0.0054)	(.0273)
2nd Quartile · Fuel Price	.0183***	-.0120***
	(.0054)	(.0273)
3rd Quartile · Fuel Price	-.0106***	.0193***
	(.0054)	(.0273)
4th Quartile · Fuel Price	.0325***	-.00534
	(.0054)	(.0273)
N	288	480
R-Square	0.9506	0.8994

Note:

1. *, ** and *** denote significance at the 5% 1% and 0.1% levels.
2. Standard errors are reported in parentheses.
3. The dependent variable in all columns is the market share of vehicle models from different quartiles.

4. Study period for the US and China are 2012 - 2017 and 2008-2017, respectively

We observe that the market share of the quartile with best fuel efficiency is positively correlated with fuel price in US. Generally, it seems when gasoline prices are higher, sales shifted from the second best (in terms of fuel efficiency) quartile to the best quartile, and from the worst quartile to the second worst quartile. Similar trends are not observed in China. This result is consistent with the previous results based on model-level sales regression, which provide further evidence that while Chinese consumers prefer vehicles with better fuel efficiency, the Chinese market is not as responsive to fuel prices as the US consumers.

5. Discussion

6.1 Insights on US/China difference in vehicle purchasing behavior

The results of our analysis show that there is a major difference between US and China with regard to the impact of gasoline price on vehicle preferences. In the US, even though consumers prefer vehicles with lower fuel consumption rates, this preference is sensitive to gasoline prices. Gasoline price increases significantly boost the sales of less efficient vehicles, while gasoline price drops significantly raise the sales of more efficient vehicles. This is consistent of our predictions in the theoretical section. However, in China we do not observe the same trend. Despite the results revealing that Chinese consumers value fuel consumption rate, impacts of gasoline price changes on vehicle preferences are not what our theoretical framework expected, in that their consumers do not respond to changes in fuel prices by favoring fuel efficiencies.

There are several possible reasons for this difference. First, China and US have different discount rates when considering future income. China has a much higher interest rate than the US due to higher capital gain and lower capital supply. The 10 Year Treasury Note interest rate in December 2017 is 2.375% in US[41], and 3.915% in China[42]. Therefore, future savings are not as valuable as in the China, since saving money now could yield more income in the future and sacrifice future for now is less cost effective. Besides, in a society with high economic growth in the past 30 years, people have experience of high personal wealth growth, therefore future savings will not matter as much since personal financial standing might improve quite a lot in the future.

Secondly, China has a much lower VMT per vehicle than US. The Chinese national average VMT per vehicle is not publicly available. The average miles driven per vehicle in Beijing in 2015 is 11495 km[43]. The national average is likely to be lower than this[44]. In US, the national average miles driven per vehicle is 10924 miles (17580 km) in 2017[45], which is 53% higher than the Beijing average in 2015. As previous analysis shows, lower VMT means less fuel cost and less fuel cost savings as well. Therefore, vehicle fuel consumption rates do not contribute to fuel savings as much as in the US.

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[41] Retrieved from https://www.cnbc.com/quotes/?symbol=US10Y

[42] Retrieved from https://cn.investing.com/rates-bonds/china-10-year-bond-yield

[43] 2015 年北京交通发展年报(2015 Beijing Transportation Development Annual Report), Beijing Transportation Development and Research Center, March 3, 2016.

[44] 小熊油耗车主 2017 年度用车报告(Bear Fuel Consumption Users 2017 Usage Report), Bear Fuel Consumption, August 29 2018.

[45] 2017 National Household Travel Survey: Summary of Travel Trends, U.S. Department of Transportation Federal Highway Administration

Third, since Chinese vehicle ownership penetration has only reached the mainstream group of consumers recently (Huo and Wang 2012), and vehicle sales have been still rising in the past decade, many car buyers are still first-time buyers. These consumers may not realize that the future fuel cost is a major part of life cycle automobile ownership cost, thus they would tend to overlook these costs and be less sensitive to gasoline price changes.

Finally, our assumption that consumers only consider the gasoline price at the time of purchasing the vehicle might not hold in China. If Chinese consumers instead think fuel price in the long term fluctuates around a constant value (because the gasoline price is heavily regulated by the central government), any increase or decrease of gasoline price in the short term would not cause Chinese consumers to re-evaluate long-term fuel savings. Future studies are needed to examine these different hypotheses and better explain why consumer choices in China are not affected as in the US with respect to fuel price changes.

One thing to notify is, the reason Chinese consumers are not responsive to the gasoline change in the expected way is probably not because they have higher income than US consumers.

The average pre-tax household income in US is $81283[46]. Assuming this household is in the biggest US state California, the disposable income after income tax and social security payment would be $66483[47].Using the mean MPG of vehicle sold at 24.6 miles per gallon and gasoline price at $2.55/gallon (December 2017 price), with annual VMT at 10924 miles, that is $1132 in annual

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[46] American Community Survey (ACS)2017, United States Census Bureau

[47] Tax Foundation, https://taxfoundation.org/2018-tax-brackets/, https://taxfoundation.org/2019-state-individual-income-tax-rates-brackets/

fuel cost, which is 1.7% of the national average household income.

The average disposable income (after income tax and social security payments) per capita in China in 2017 is CNY￥25973.8, with on average 3.05 persons in one household, that is CNY ￥79220, or US$11785[48]. Using the mean fuel consumption rate at 6.9L/100km and gasoline price at CNY￥6.84/L (December 2017 price), with annual VMT at 11495 km, that is CNY￥5425 or US$807 annual fuel cost, which is 6.85% of the national average household income. Considering on average 100 households only owns 29.7 motor vehicles in China in 2017, the car buying households in China might be wealthier than national average. If we use the average disposable income per capita for the top 30% households, household income becomes US$25397. Annual gasoline spending is 3.2% of annual disposable income, still much higher than US.

6.2 Policy Implications

The results also provide insights on related automobile energy policy. As our study shows, US consumers are relatively sensitive to gasoline price changes. Using the coefficient of fuel price interacted with fuel consumption rate on log sales, we know that when the fuel price increases by 1 percent (2.55 cents based on December 2017 prices), the vehicle sales decrease by 0.338 percent. In the long run, this would translate into a 0.338 percent decrease in light duty vehicle stock, which is equivalent to reduction of 837,023, based on number of registered light duty vehicle in 2016[49].

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[48] China Statistical Yearbook 2018, National Bureau of Statistics of China

[49] Bureau of Transportation Statistics, Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances https://www.bts.gov/content/number-us-aircraft-vehicles-vessels-and-other-conveyances

Based on the average miles driven annually[50], average fuel consumption rate, and carbon emission per gallon of gasoline, US annual carbon dioxide emission could be reduced by 53.6 million metric tons[51].

In addition to reducing sales of automobile, increased gasoline price also changes the vehicle mix sold and increase the sales-weighted average fuel consumption rates. Based on the results in section 5.2, we could calculate that with a 2.55 cent increase in fuel price, the average fuel consumption rate could reduce from 9.287L/100km to 9.28L/100km, which contributes to a 11.13 million metric tons of carbon emission reduction.

The two effects add up to a total of 64.7 million tons of carbon emission reduction, which is a bit less than 1% of national carbon dioxide emission in 2018[52]. This implies that gasoline tax is an effective tool to improve vehicle fuel economy and reduce fuel consumption.

We could also evaluate this effect in the framework of a carbon tax. Using the baseline gasoline consumption at 352 million tons a year, the increase of total collected tax for 3 cents per gallon gasoline tax is $2,374 million US dollars, which is equivalent to a cost of $36.7 per ton of carbon dioxide emission reduction.

This calculation, however, has not taken into account the impact of gasoline price increase on

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[50] 2017 National Household Travel Survey: Summary of Travel Trends, U.S. Department of Transportation Federal Highway Administration

[51] Physical and chemical properties of gasoline: Department of Energy (DOE), Alternative Fuels Data Center (AFDC), Properties of Fuels.

[52] Inventory of U.S. Greenhouse Gas Emissions and Sinks, United States Environmental Protection Agency, https://www.epa.gov/sites/production/files/2019-02/documents/us-ghg-inventory-2019-main-text.pdf, retrieved on 3/15/2019.

VMT reduction yet. Based on a study by Puller and Greening (1999), one percent increase in gasoline price also leads to a 0.35 percent decrease in VMT in the long run, which translates to 55.3 million metric ton of carbon emission reduction. After adding this effect, the cost per ton of carbon emission reduction reduces to only $19.8.

We could evaluate this effect in the framework of a carbon tax. Using the same numbers above, the effects in carbon emission reduction of 3 cents per gallon gasoline tax is equivalent to a tax of $2.52 per ton of carbon dioxide emission reduction. Since the social costs of carbon emission is evaluated at $36 in 2015[53], this is a very cost-effective measure to reduce carbon emissions.

We could also compare the effects of gasoline tax with other policies like the CAFE standards. Krupnick et al (1993) estimated that for each ton of reduction in carbon emission, there is a migh higher $106 cost.

However, since the regression results show that Chinese consumers are not responsive to gasoline prices, despite being a good tool that collect fees based on road usage (although Chinese highways collect tolls as well), a gasoline tax itself wouldn't be sufficient to affect vehicle purchasing behavior. Other tools like a feebate policy, purchase taxes or fuel economy standards would be needed (Brand et al 2013).

Our results have implications for other countries as well. Response to gasoline price changes apply to other countries: high discount rates related to high economic growth, and unfamiliarity

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[53] Current Technical Support Document (2016): Technical Update to the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order 12866, United States Environmental Protection Agency https://archive.epa.gov/epa/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf

with concepts of life-time ownership costs related with recent vehicle ownership penetration, might also exist in other developing countries like India. Therefore, fuel tax might not be an effective mechanism to change the average fuel economy of vehicles in these countries. Policies like a feebate system might be needed for that purpose.

6. Conclusion

This study did a comparative analysis of US and China automobile market using historical vehicle sales data linked with gasoline prices and vehicle attributes including fuel consumption rates. The results reveal a major difference in vehicle purchasing behavior between US and China. US consumers are strongly affected by fuel price and purchase vehicles with better fuel economy more when gasoline prices higher and vice versa, while the Chinese consumers do not seem to be affected by gasoline price changes much. This difference indicates fundamental differences in vehicle usage and capital return rate, and implicates different suitable policy to reduce fuel consumption in the two countries.

Even though this study does not apply any new methodology with regard to analyze how consumers value future fuel saving and how gasoline price changes affect automobile market, it could still add to the existing literature as it uniquely separately estimates the correlation between both gasoline price and fuel consumption rate and market performance in two countries in a comparable way. The two countries selected in this study are not only the two largest automobile markets that have largest energy and emission impacts, but could also represent the difference between developed and developing countries.

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