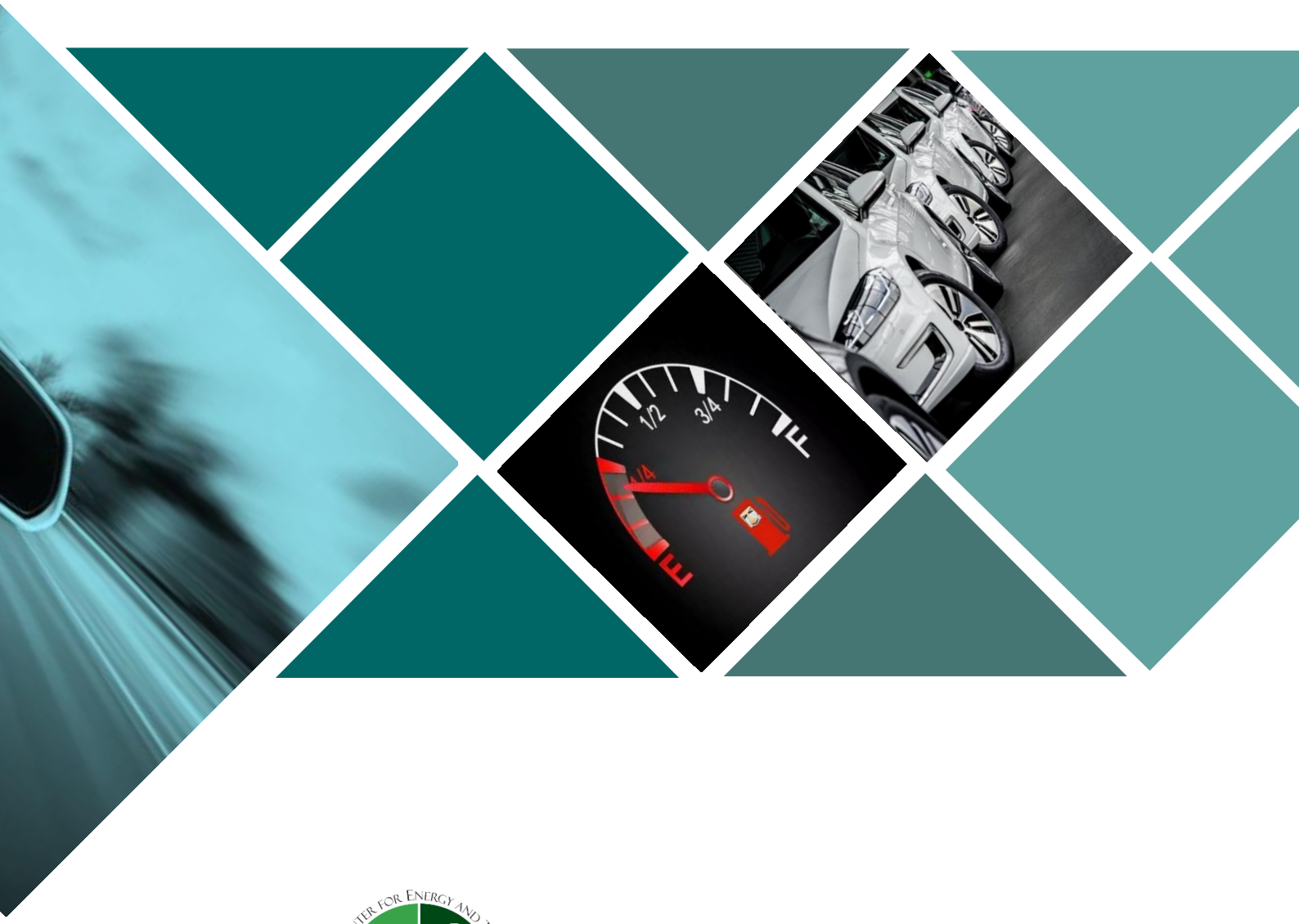
2017 Passenger Vehicles Actual and Reported Fuel Consumption: A Gap Analysis



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Glossary of Terms

LDV	Light Duty Vehicles; Vehicles of M1, M2 and N1 category not exceeding 3,500kg curb-weight.
Category M1	Vehicles designed and constructed for the carriage of passengers comprising no more than eight seats in addition to the driver's seat.
Category M2	Vehicles designed and constructed for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum mass not exceeding 5 tons.
Category N1	Vehicles designed and constructed for the carriage of goods and having a maximum mass not exceeding 3.5 tons.
Real-world FC	FC values calculated based on ***BearOil app*** user data input.
Certified FC	Prior to sale in China (either domestic produced or imported cars), the vehicle is certified according to the "light duty vehicle FC testing method" standard (GB/T19233). The fuel consumption result combines, urban and rural fuel consumption tests.
Entity vehicle	Vehicle registered by companies and/or government.
Effective figure	While each of the models assessed in this study has an actual average FC based BearOil app user input (calculated as $M = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n}$), an average variance is used for deciding whether or not the average figure is robust enough to be used (calculated as $s^2 = \frac{(x_1 - M)^2 + (x_2 - M)^2 + (x_3 - M)^2 + \cdots + (x_n - M)^2}{n}$). In this study we only use data in the range $M-2s^2 <data<M+2s^2$.
Private vehicle	Vehicle registered for private use.
Commercial vehicle	Freight vehicles and vehicles with over nine seats (including driver's seat); see GB/T3730.1-2001 for more details.
Passenger vehicles	All vehicles with up to nine seats (including the driver's seat); see GB/T3730.1-2001 for more details.
NEDC	New European Driving Cycle
MIIT	Ministry of Industry and Information Technology
IEA	International Energy Agency

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Study Highlights

With the sustained and rapid socio-economic development of China, passenger vehicle ownership continues to grow. According to the Ministry of Public Security Traffic Management Bureau, as of the end of March 2017, the national motor vehicle volume exceeded 300 million for the first time. Passenger cars made up 200 million of that number.[1] As of the end of June, national car ownership reached 205 million, with 23 cities having over 2 million registered cars. Not surprisingly, China's rate of dependence on foreign oil rose to 65.5% during 2016[2], a record high, putting increasing pressure on energy supply as a prominent issue. As a means to promote the development of vehicle energy-saving technology, reduce vehicle fuel consumption and greenhouse gas emissions, and align with global policies, China entered the fourth phase of its "passenger car fuel consumption standard" at the beginning of last year, targeting 5.0 L/100km by 2020.[3]

China's existing fuel consumption management standards and policies are based on the European NEDC driving cycle, despite stark differences between driving conditions in these two locations. In fact, there are even differences in driving conditions among Chinese cities.[4] Such differences stem from the followings three issues: (1) There is a noticeable difference between simulation driving and actual road driving conditions, given China's various road infrastructure developmental stages; (2) It is the vehicle manufacturer that reports the result of the test after cautious selection of the car that will be tested and the particular FC results after conducting several tests; (3) The test does not include clear external vehicle conditions requirements such as altitude, outside temperatures (particularly when below -7°C), air conditioning, tire air pressure, driving habits, and other factors that could greatly impact actual FC. To this end, the Ministry of Industry and Information Technology (MIIT) issued "China's new energy vehicle product monitoring research and development" project, commissioned by the China Automotive Technology Research Center (CATARC) and executed between February 2015 and December 2017. The goal of the project is to produce a draft of China's Auto Test Cycle (CETC) that will be tested between 2022 and 2023. Final work conditions will be determined and enforced by 2023.[5]

In collaboration with the BearOil app, *i*CET has been evaluating the gap between reported and actual FC for three consecutive years since 2015. This year, the analysis is based on the actual fuel consumption data voluntarily reported by nearly 800,000 car owners, covering 31 provinces and cities nationwide, and including over 10,000 car models (model year 2008 to 2016). The differences between actual and reported fuel consumption of vehicles according to their classification, brand, and usage region and season, is investigated. The findings from this year's report are below:

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[1] China's vehicle number exceeding 200 million, 23 cities exceeding 2 million respectively. *Auto ifeng* (2017-09-04) http://auto.ifeng.com/quanmeiti/20170719/1092757.shtml

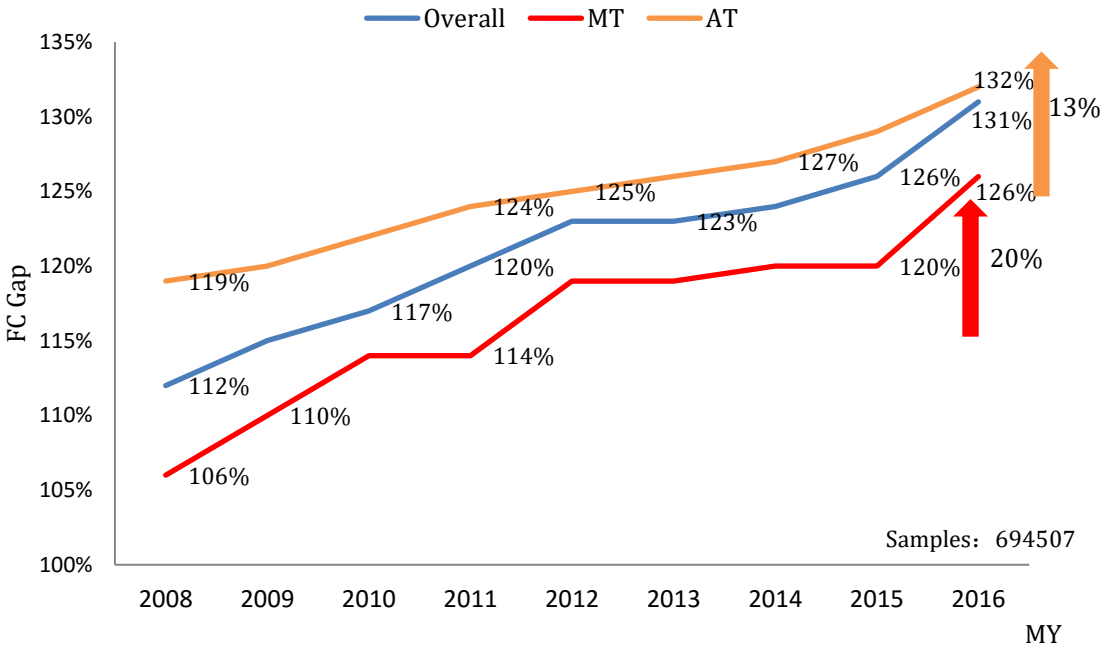
[2] China's dependence degree on crude oil import climbed to a recording level of 65.5%. *Sina*. (2017-09-04） http://finance.sina.com.cn/chanjing/cyxw/2017-01-13/doc-ifxzqnip0959975.shtml

[3] CAFC Phase IV Standard Interpretation. *MIIT*. (2017-06-28) http://www.miit.gov.cn/n1146285/n1146352/n3054355/n3057585/n3057589/c3616982/content.html

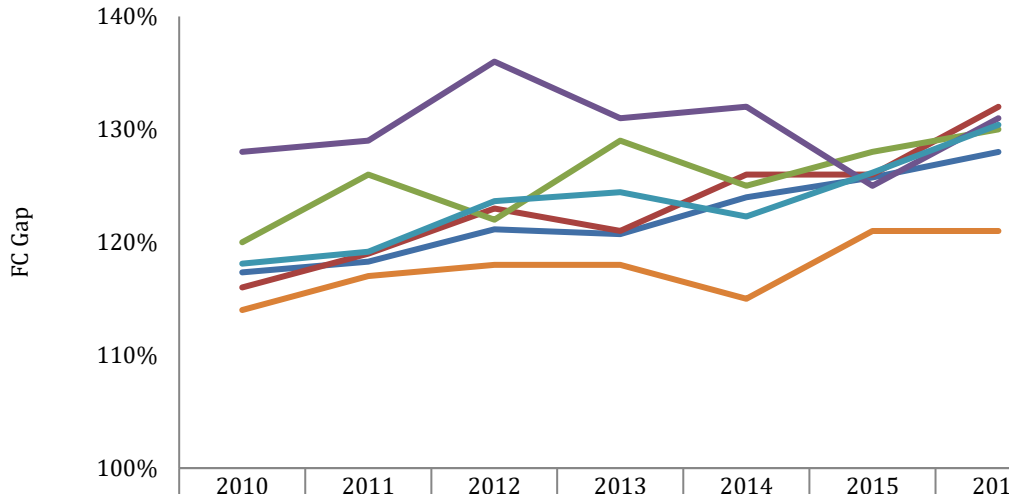
[4] From Laboratory to Road-A 2017 update. *ICCT*. (2017-11-06) http://www.theicct.org/sites/default/files/publications/Lab-to-road-2017_ICCT-white%20paper_06112017_vF.pdf

[5] China's own testing cycle standard research is nearly finalized. D1EV (2017-09-04) https://www.d1ev.com/news/zhengce/55876

1. **FC gap gradually increased from 2008 to 2016 as the share of Automated Transmission (AT) cars grew; China's FC gap is expected to grow as AT shares of new vehicle sales grow.**

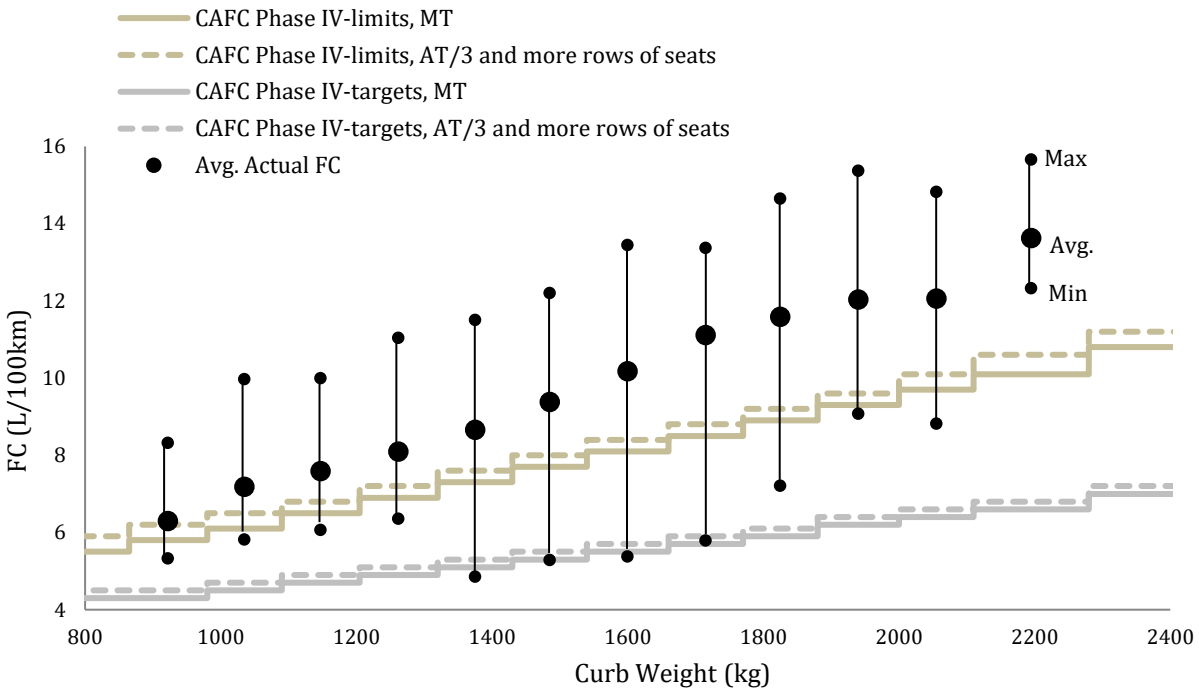


2. **By-segment FC gaps have increased at different paces from 2010 to 2016; Medium and MPV model FC gaps grew the least, while SUV and compact segments saw the largest gap increase. Because SUV FC gap and market share grows steadily, this segment is likely to further drive market FC gap increase.**



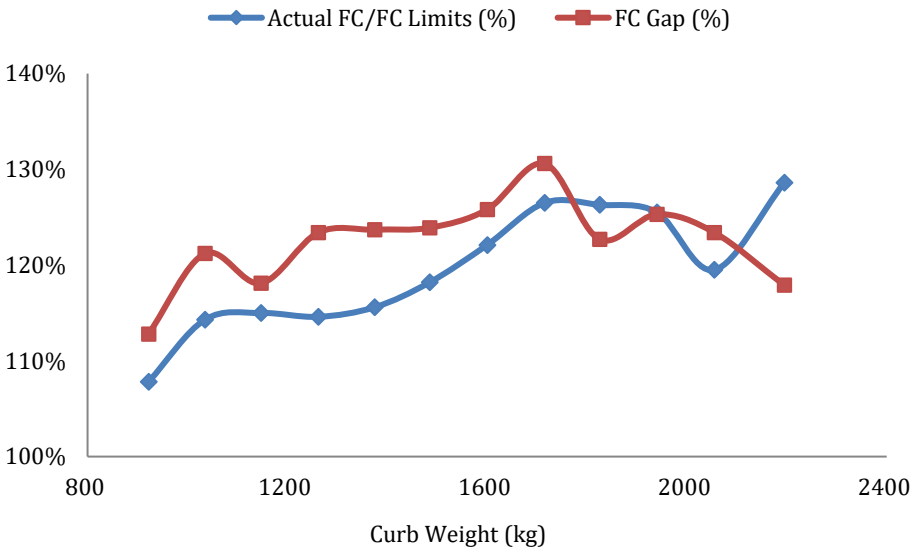
	2010	2011	2012	2013	2014	2015	2016
Small	117%	118%	121%	121%	124%	126%	128%
Compact	116%	119%	123%	121%	126%	126%	132%
Mid-size	120%	126%	122%	129%	125%	128%	130%
Large	128%	129%	136%	131%	132%	125%	131%
SUV	118%	119%	124%	124%	122%	126%	130%
MPV	114%	117%	118%	118%	115%	121%	121%

3. **The average actual FC of vehicles in all mass ranges (large black dot in the below figure) is higher than the corresponding weight-bin based FC standard limit (golden stepped line in the below figure).**



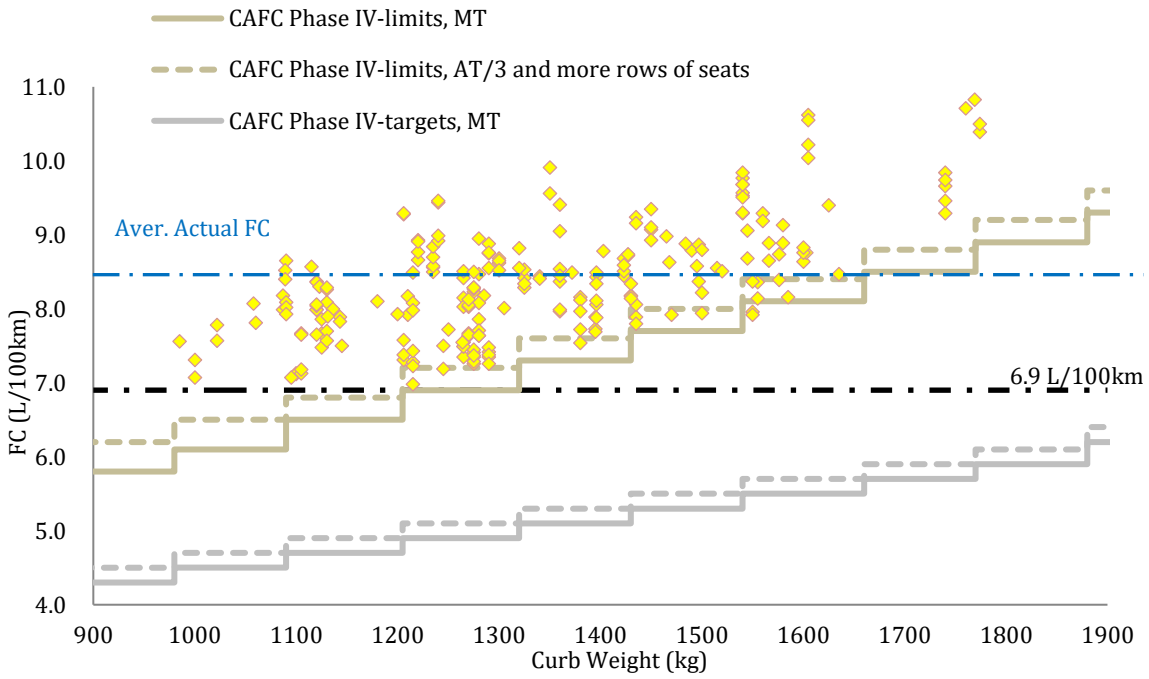
***Note**: Weight ranges with actual FC sample size smaller than 900 and less than five vehicle models are excluded from the analysis.*

4. **While the gap between the actual FC of vehicles and the FC reported by the manufacturers (red line in the below figure) is very clear but overlooked by policy-makers, our analysis demonstrates that the gap between the actual FC of vehicles and their standard limit (blue line in the below figure) is too wide to be considered negligible. In particular, vehicles weighing over 1600kg tend to have higher FC deficiency, suppressing 120% -- a gap that should alert policy-makers. This calls for proper evaluation and enforcement of the standard.**



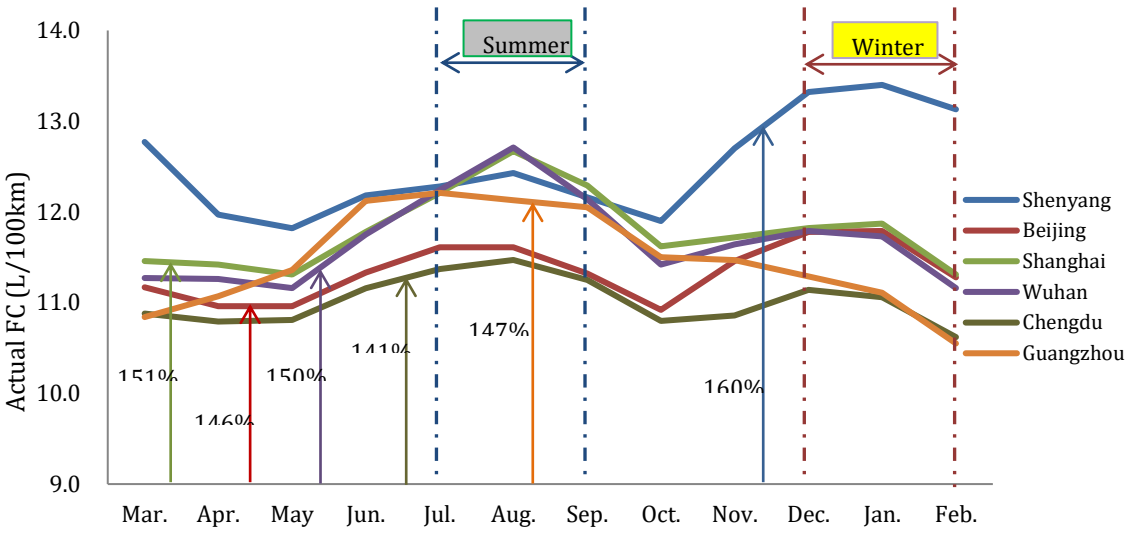
***Note**: Weight ranges with actual FC sample size smaller than 900 and less than five vehicle models are excluded from the analysis.*

5. **The analysis exemplifies the finding that the majority of models that reported meeting their FC limit did not even meet their own (typically higher) FC requirement. For example, the average actual FC for vehicles that reported to have 6.9L/100km -- the national target for the year 2016 -- was actually 8.4L/100km. While the standard limit was believed to have been successfully met on average (according to reported data), it actually was not.**

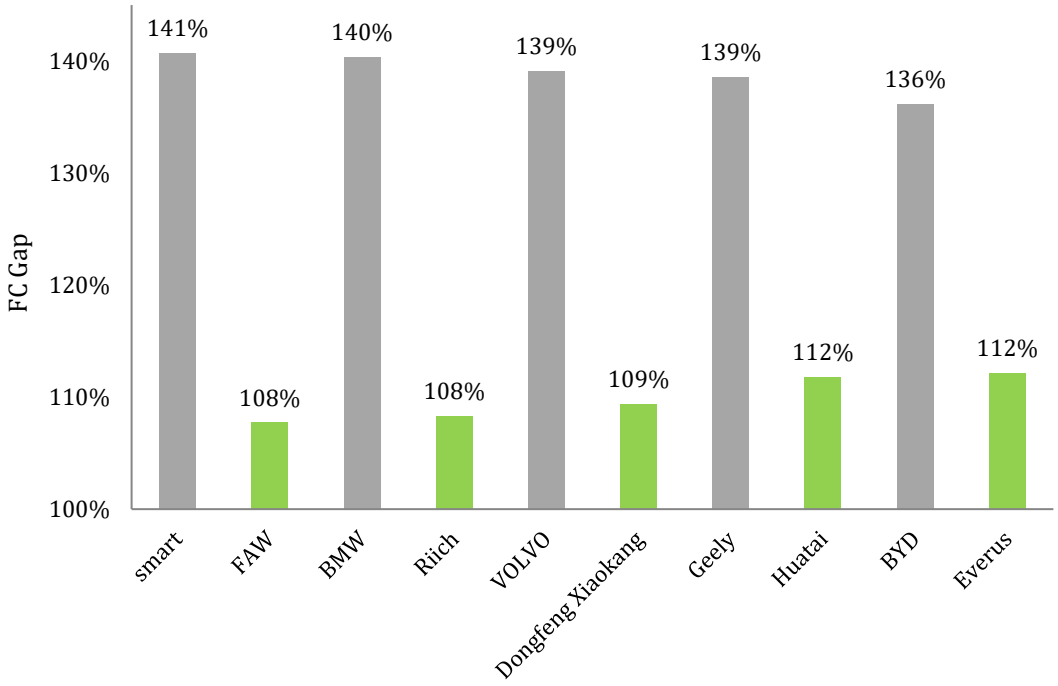


***Note**: Each yellow diamond in the figure represents a singly vehicle model; each model FC is based on the average of data inputs for that model collected between 2010 and 2016 from various users and various location in China.*

6. **Spatial factors significantly affect the FC gap. Actual FC in the eastern coastal provinces and cities is higher than the southwest region. Temporal variations are also significant. Within the same location, summer tends to bring higher FC gaps for southeastern regions while winter increases FC gap in northern regions.**

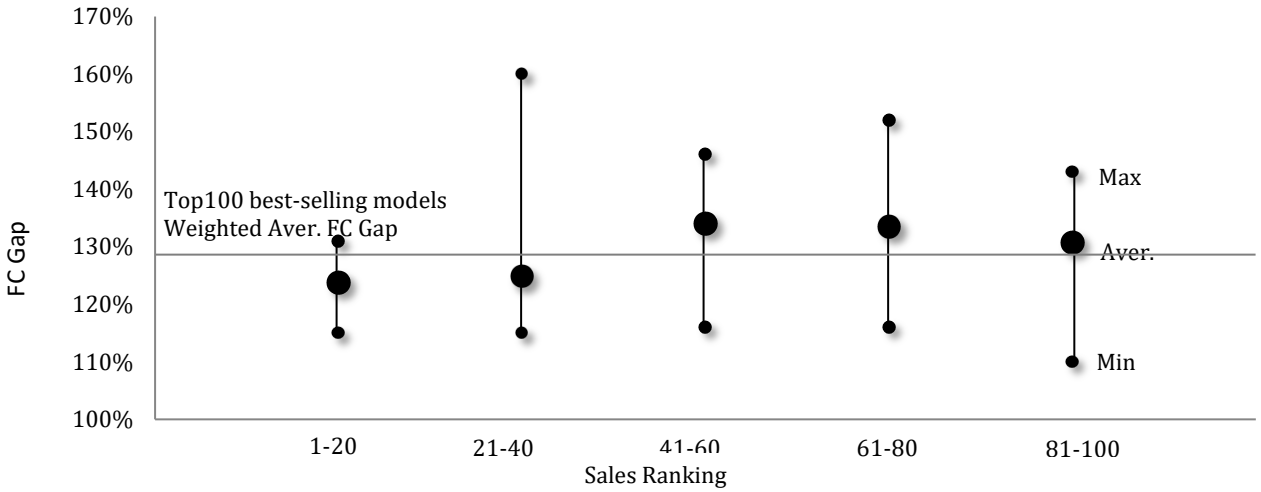


7. **There are significant differences in FC gaps between different car brands; Smart had the largest FC gap (141%), while FAW had the lowest FC gap (108%). The below figure shows the five best (green) and five least performing (grey) brands in terms of FC gap.**

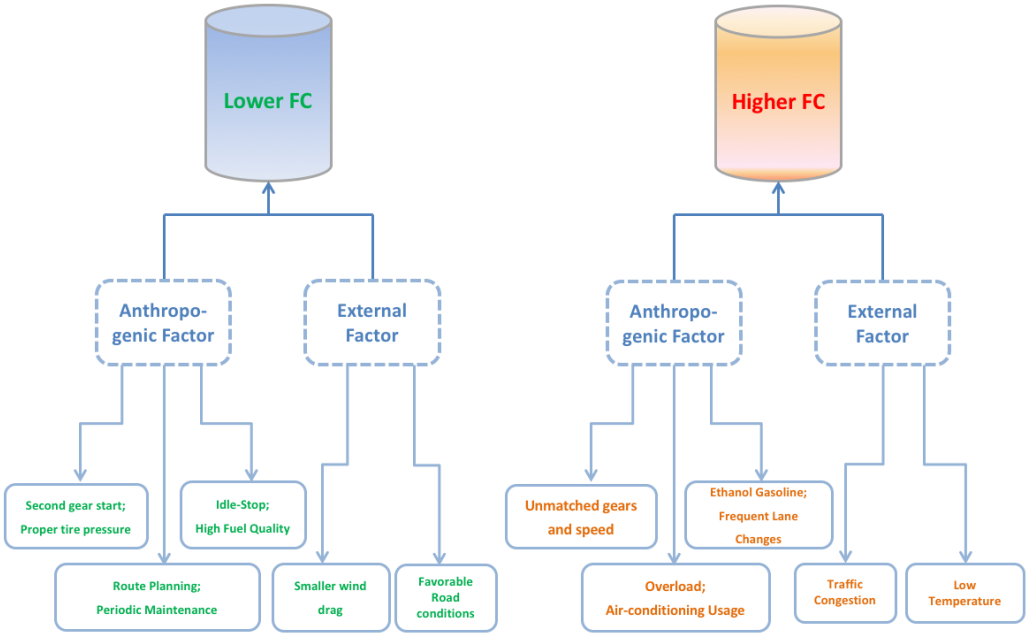


***Note**: Brand analysis is based on data from 2008 to 2016.*

8. **China's 2016 top 100 selling cars saw an average FC gap of 129%, with outliers reaching 160% and 110%; luckily, on average, the top 40 selling brands were below the average FC gap (about 124%), indicating market growth may be driven by models with lower FC gaps.**



The factors that affect the difference between the actual FC and the reported? FC can generally be divided into human factors and external environmental factors. The human factors include driving habits (speeding habits, gear shaft, etc.) and vehicle condition (car load, tire status, air conditioning usage, etc.). The external environmental factors can be divided to road conditions, traffic conditions, and local climatic conditions. The following figure summarizes some of the common factors that lead to differences in actual FC and reported FC gaps. Although isolating each factor in order to gain a clear understanding of its gap impact is a very challenging task (and beyond the scope of this work) drivers are encouraged to share their actual FC. At the policy level, to avoid data fraud, it is recommended that the government introduce a third party independent agency to carry out inspection and supervision of vehicle fuel consumption and as part of the fuel consumption certification process.



By exposing the gap between reported (certified) and real-world FC, it is possible to advocate for standards that reflect a more informed design and enforcement mechanism. This study attempts to

contribute to a more accurate framework towards low-carbon vehicle growth and better air quality in urban development. It does so by challenging the credibility and effectiveness of the governance over current traditional vehicle fuel economy.

1. Background

In 2016, propelled by China's rapid economic growth, China's oil dependence increased to 64%, a new record high.[6] Gasoline- and diesel-fueled transportation reached 55% of China's oil demand, and accounted for 70% of the increase in China's oil demand. As car ownership rates gain pace and become a significant source of urban air pollution and climate change, the automotive industry has been required to advance its technological energy-saving competitiveness and meet gradually increasing fuel consumption standards.

As of January 1, 2016, the fourth phase of China's passenger car fuel consumption standards started implementation aimed at establishing a national average of 5L/100km by 2020 or 120g/km (for more details see: 2016 Annual CAFE Report, *i*CET).[7] In June 2017 a near-final draft structuring flexibility mechanism in meeting the CAFC target was released.[8] China's "Fuel Consumption Label for Light Vehicle" (GB 22757), aimed at enhancing consumer's fuel efficiency and fuel cost saving awareness. Enforced beginning in July 2009,[9] the policy underwent revisions led by the Auto Standard Research Institute, operating under China Automotive Technology and Research Center (CATARC). A new draft standard was released by the Standards Administration Council (SAC) in June 2017 featuring two new labels – one for ICE vehicles and another for hybrid vehicles.[10]

Governance over China's FC standard is built on the lab-based test cycle in accordance with the light vehicle fuel consumption test method (GB/T19233-2008) that has been used since February 2008 and has been made publically available through the light vehicle labeling regulation (GB19578-2004) since 2010. However, this lab-based FC measurement test method is prone to bias stemming from: (1) its adherence to the New European Driving Cycle (NEDC) for measuring local fuel consumption in its type approval test, (2) the test is conducted several times on select vehicles with the best result reported, (3) the test does not account for external variations in altitude and temperature, nor local driving styles (assuming there are differences in driving styles between locations within China).

This study reinforces the observation that fuel consumption depends on driving conditions related to both (1) anthropogenic factors (e.g. acceleration, air conditioning usage, car load, tires pressure etc.) and (2) external driving conditions (road elevation, outside temperatures, traffic congestion etc.). Both sets of factors influence the real FC rate, creating variations between locations for different vehicle models and driving terrain. The International Council for Clean Transportation (the ICCT) examined the gap between the reported and actual FC in seven European cities and found a widening of the gap by 9% in 2001 to 42% in 2015.[11] That and similar studies point to a new suggested Real Driving Emissions (RDE) based on the Portable Emissions Measurement System (PEMS) test advocated for by

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[6] China's dependence degree on crude oil import climbed to a recording level of 65.5%. *Sina*. (2017-06-28) http://finance.sina.com.cn/chanjing/cyxw/2017-01-13/doc-ifxzqnip0959975.shtml

[7] Kang Liping, Maya Ben Dror, Qin Lanzhi et al., Annual report 2016 of China's passenger vehicle fuel consumption, iCET. http://www.icet.org.cn/admin/upload/2016092350679321.pdf

[8] http://www.chinalaw.gov.cn/article/cazjgg/201706/20170600483234.shtml

[9] Announcement from Certification and Accreditation Administration of People's Republic of China. *CNCA* (2017-06-28) http://www.cnca.gov.cn/xxgk/ggxx/ggxx2009/201512/t20151230_44447.shtml

[10] Notice on holding publicity meeting for Light-Duty Vehicle Energy Consumption Label Standard and Light-Duty Commercial Vehicle Fuel Consumption Limit Standard. *Auto branch of China Standardization Association* (2017-06-28) http://www.catarc.org.cn/NewsDetails.aspx?id=2860

[11] From Laboratory to Road-A 2017 update. *ICCT*. (2017-11-06) http://www.theicct.org/sites/default/files/publications/Lab-to-road-2017_ICCT-white%20paper_06112017_vF.pdf

environmental NGOs, partially inspiring the development of the Real Driving Emissions (RDE) test. China's new FC label released in 2017 (GB 22757-2017) emphasizes the fuel consumption level of vehicles in urban areas, because it recognizes the robustness of this value over the general FC reporting. Therefore, in future studies, we will also examine the actual fuel consumption against urban report fuel consumption.

This study aims to assess the gap between reported and real-world FC and therefore uses the reported FC data available on the MIIT's website[12] and a bottom-up actual FC data collection app, BearOil app (小熊油耗).[13]

2. Data

This study analyses gaps between actual and certified FC levels across vehicles and locations in China, and identifies potential reasons for these gaps. The study uses two sources of data: (1) reported, lab-based or certified FC figures available on the Ministry of Industry and Information Technology (MIIT) website,[14] also mandated to be displayed on a car front window upon purchase; and (2) new, in-use actual FC data collected by the BearOil app. This section briefly introduces the former and then describe the latter in detail.

2.1 Lab-based FC Data

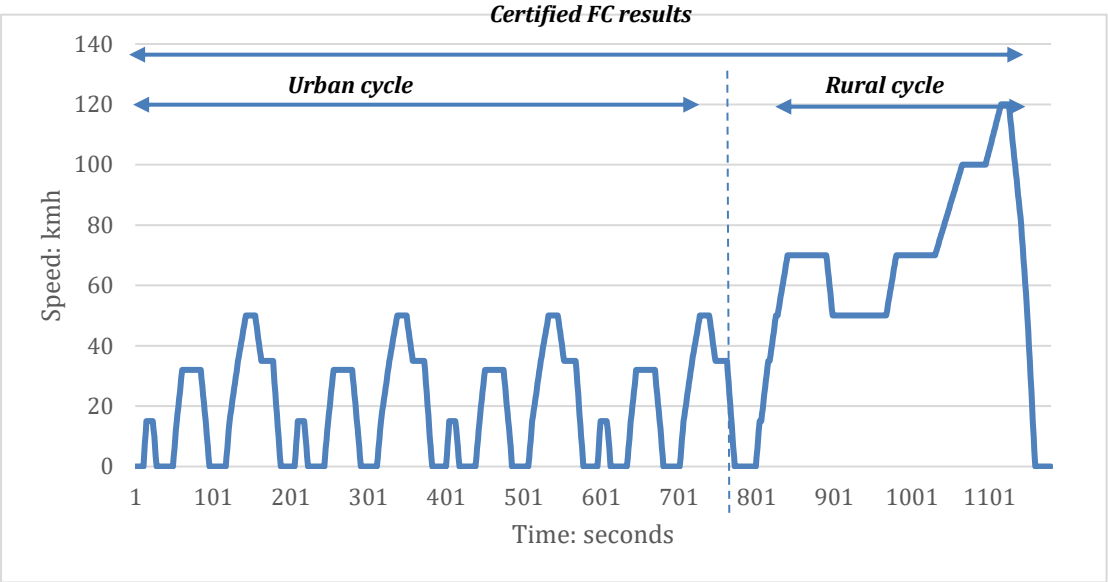
In 2009, MIIT released the light vehicle FC labeling regulation requiring every M1, M2, and N1 category vehicle sold in China fueled by either gasoline or diesel and with a curb-weight not exceeding 3500kg to be labeled with its approved fuel consumption test results.[15] Under the regulation, domestic automobile producers and imported car dealers are required to follow the "light vehicle fuel consumption test method" (GB/T19233) performed by certified testing sites across China[16] to confirm the vehicle's projected fuel consumption data.

FC test results conducted by the vehicle manufacturer or its representative are submitted to the testing agency responsible for the type test. Through a test with simulated urban and suburban driving conditions representative of typical driving conditions, carbon dioxide (CO_2), nitric oxide (CO) hydrocarbon (HC) emissions as well as fuel consumption are calculated through a carbon balance method[17] by the authorized test site. The figure and table below demonstrate China's typical driving cycle (test cycle speed per second divide), which is based on the EU test cycle (NEDC). The labeling

[12] MIIT-Vehicle fuel consumption website. http://chinaafc.miit.gov.cn/n2257/n2280/index.html
[13] BearOil (Xiaoxiong) app. http://www.xiaoxiongyouhao.com/
[14] http://chinaafc.miit.gov.cn/
[15] Light vehicle labeling regulation. *Baidu Baike*. http://baike.baidu.com/link?url=wnlq8kE1YketxI8ll2Y_fwGQXDe5DTXgkvjIpocbvzeDtHOc-1241_qDbzyfdMLcwAnoEWSGhgqJrRprKVc3DK
[16] Capacity of national vehicle test organizations authorized by MIIT. *Vehicle Technique Service Center of China*. http://www.cvtsc.org.cn/cvtsc/zhxx/572.htm
[17] GB19233-2008 Light vehicle fuel consumption test method. *MIIT-vehicle fuel consumption website*. http://chinaafc.miit.gov.cn/n2257/n2340/c79073/content.html

system allows a 4% fuel consumption gap between a model FC and its first model series FC score. All M1 vehicles with similar vehicle curb-weight and vehicle components produced by the same manufacturer are authorized to use the same FC level.

Figure 1: China's type test driving conditions



***Note**: The accuracy of China's driving cycle is under debate and a non-NEDC cycle will likely be released soon.*[18]

Table 1: China's FC type test divide

Test information	Suburban	Urban	Combined	% of total test time
Idling (S)	40	240	280	24%
Clutch disengagement (S)	10	36	46	4%
Shift (S)	6	32	38	3%
Acceleration (S)	103	144	247	21%
Cruise (S)	209	228	437	37%
Brake (S)	32	100	132	11%
Max. speed (km/h)	120	50	N/A	N/A
Average speed (km/h)	62.6	19	33.8	N/A
Max. acceleration (km/h/s/)	3.7	3.0	3.2	N/A
Average Acceleration (km/h/s)	1.4	2.7	2.2	N/A

With variations in driving conditions depending on both the driver's preferences and external elements (road elevation, outside temperatures, congestions etc.), real-world vehicle FC will vary between vehicles of the same model and may no longer be well represented by the labeled FC level.

[18] China's own testing cycle standard research is nearly finalized. *D1EV* (2017-09-04) https://www.d1ev.com/news/zhengce/55876

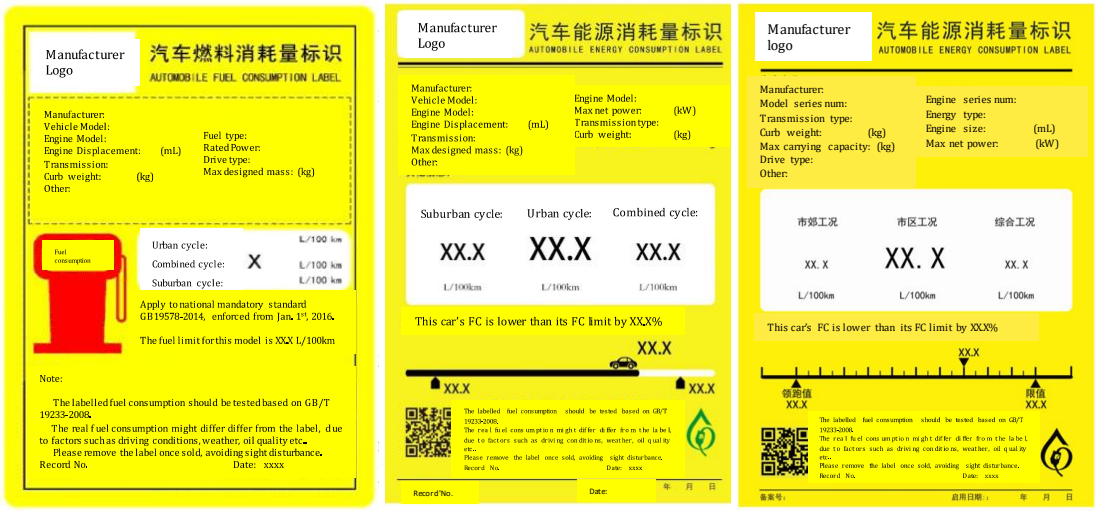
Figure 2 illustrates China's FC test cycle results as reported by the MIIT and on the official labels meant to be placed on the front window of vehicles for sale.

Figure 2: FC reporting on the MIIT website

MIIT website: http://chinaafc.miit.gov.cn/n2257/n2263/index.html

On May 2017, the national standard committee announced an updated version of the light vehicle FC labeling standard (GB 22757.1 / 2-2017). Compared with the previous label, the new label further highlights the vehicle's FC in urban conditions. Urban test FC results are in principal closer to the real driving conditions for most vehicles. The new label will be implemented January 1, 2018. **Figure 3** compares the design and content of the new and old versions of the fuel consumption logo.

Figure 3: ICE vehicle Label: GB 22757-2008 (left), GB 22757.1-DRAFT (middle), GB 22757.1-2017 (right); Partially translated to English by *i*CET



***Reference**: http://www.icet.org.cn/english/admin/upload/2017112138950337.pdf*

The FC testing method provides a detailed description of driving conditions followed by the test performing entity. There are two potential shortcomings in the test driving conditions: (1) some factors allow for high gaps in test conditions, such as vehicle mileage (3000km-15000km range) and outside temperatures, which may result in different FC scores for the same vehicle model; and (2) under real-world circumstances, driving conditions may not be well reflected in the test conditions, mainly because China has varying temperatures, topography, and urban densities to which averaging does no justice. **Table 2** highlights basic testing requirements for driving condition elements that may increase real-world and certified FC gaps.

Table 2: China's type approval cycle requirements – some "loose ends" may increase real-world and certified FC gaps

Tested parameter	Testing requirements
Type of test	Chassis dynamometer in laboratory
Test cycle	NEDC test cycle
Max. speed	120km/h
Max. acceleration	3.7(km/h)/s
Idling	24%
Vehicle weight	Curb weight+100kg
Temperature	20-30°
Tested vehicle`s driving distance	3000km~15000km
State of charge starter battery	Fully charged battery
Air conditioning	Off
Tires pressure	Following suggested tires pressure provided by manufacturer
Transmission shift schedule	Following the test regulation

2.2 New in-use FC data

2.2.1 Data provider

The BearOil app (小熊油耗) is China's first independent for-profit mobile application aimed at collecting actual voluntary FC data across China and among various vehicle models. It then publicizes the results to inform consumers, manufacturer, and policy-makers. BearOil's operational model relies on app-on commercials. Since its creation in 2008, close to 1 million drivers have downloaded the app in 31 cities, representing about 10,000 different vehicle models and covering over 7 billion kilometers driven in 30 million data points.

To conduct this feasibility and FC gap study, *i*CET joined forces with BearOil in 2015.[19] The initial study analyzed over 210,000 valid samples of FC levels reported by drivers from various locations in China between 2008 and 2014 and concluded that the average FC gap in China was 127% for 2014 models. Since then, BearOil has engaged with actual FC studies in collaboration with academic representatives (e.g. Tsinghua), NGOs (e.g. the ICCT[20]) and various companies (e.g. Gaode[21]).

2.2.2 Data representation

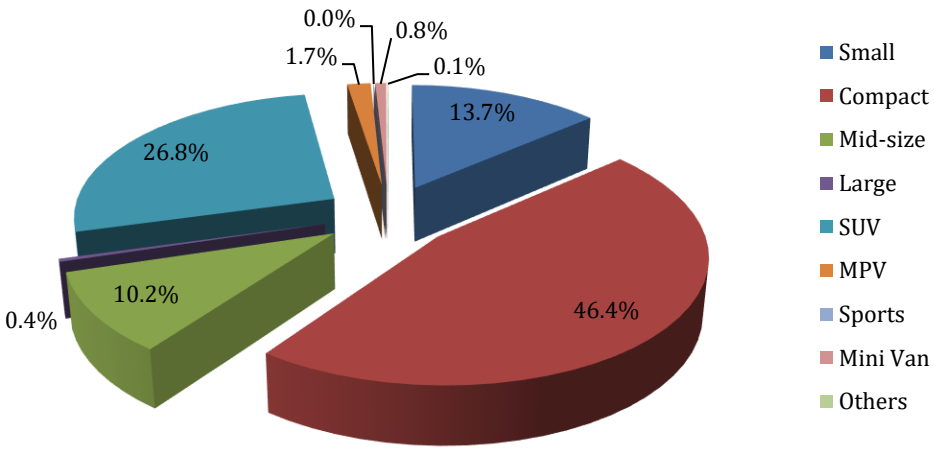
Since the app is free and aimed at delivering real-world FC calculations for cost reduction purposes primarily, it is assumed high-income vehicle owners are excluded from the pool of app users (arguably, they have little financial incentive to save on fuel), resulting in a bias towards low-mid income users. This key data representation is reinforced in the vehicle segmentation of its users (there are hardly any few sports or luxury vehicles), as demonstrated in Figure 4. However, China's in-use vehicle fleet is assumed to have a similar bias – as reflected in China's new car sales for 2016, shown in Figure 5 (SUV and MPV dominated).

[19] Xiaoxiong APP, http://www.xiaoxiongyouhao.com/

[20] From Laboratory to Road International. *The ICCT* (2017-11-06) http://www.theicct.org/sites/default/files/publications/Lab-to-road-intl_ICCT-white-paper_06112017_vF.pdf

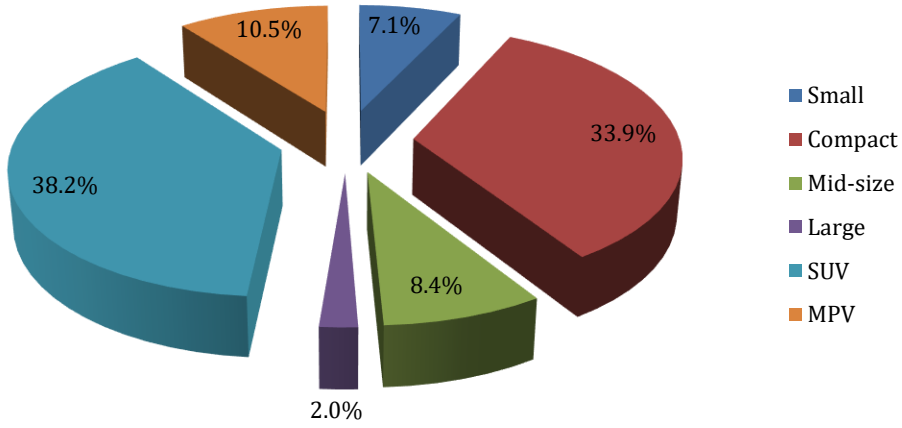
[21] 2017 Q1 Traffic analysis report of China's major cities. *A map* http://cn-hangzhou.oss-pub.aliyun-inc.com/download-report/download/quarterly_report/17Q1/2017Q1%E4%B8%AD%E5%9B%BD%E4%B8%BB%E8%A6%81%E5%9F%8E%E5%B8%82%E4%BA%A4%E9%80%9A%E5%88%86%E6%9E%90%E6%8A%A5%E5%91%8A-final.pdf

Figure 4: BearOil by-segment user breakdown



Note: *Mini cars (A00-type) are included in the Small segment.*

Figure 5: China by-segment user breakdown as reflected in 2016 new car sales



Note: *Mini cars (A00-type) are included within the Small vehicle segment.*

2.2.3 Data collection practices

For the initial use, after the empty tank warning light turns on, app users will fill their vehicle tank until full. The user records (1) the fuel price paid (it then calculates the volume based on China's united

fuel cost), and, (2) the distance driven. From the second time onward, the app uses stored user data to calculate the user's fuel consumption, based on a simple insertion of fuel cost and distance. For example: a user has inserted a mileage of 4236 when filling his gas tank on May 5. On June 6, the user filled his tank again after the gasoline light appeared, this time the mileage showed 5041. Therefore the app recognizes a distance of 5041km-4236km=805 was driven using 60 liters of gasoline: 60/(805)*100=7.45L per 100km driven.

Figure 6: App snapshot

A BearOil app user can compare his or her own vehicle FC performance with the FC results of users that drive the same vehicle model, or any other vehicle model that has the same engine displacement. Since each driver and app user is dependent on his or her unique actual driving conditions, including anthropogenic and external factors, the app enables the performance of simple comparisons between FC scores of the same model or engine displacement in various locations in China.

2.2.4 Data cleaning

Given the potential errors in BearOil's data derived from manual app usage (fuel and mileage figures insertion), a data cleaning process is needed. The sample data used in this study excludes the followings:

- Models that have less than 20 valid user-data samples (user sample is based on at least three data inputs).
- Data input with incomplete model information (for example, AT/MT).
- Vehicles with average FC higher than double the variance range.

As much as 92% of the data met the above requirements and entered the sample employed in this study. Also, 2016 MY samples account for 0.39% of the total passenger vehicle sales volume in 2016.

Table 3: 2016 actual FC data

Model Year	Total Vehicle Models Covered	% of Annual Passenger Vehicle Sales
2008	18,414	0.27%
2009	26,999	0.26%
2010	38,187	0.34%
2011	59,212	0.41%
2012	87,619	0.56%
2013	136,759	0.76%
2014	114,598	0.58%
2015	117,578	0.56%
2016	95,141	0.39%
Total	**694,507**	

The 2015 BearOil app added driving conditions and received feedback from a total of over 18,000 users. The feedback was interpreted to indicate that over 62% of respondents use routes with heavy traffic over 60% of driving time. This information is rather limited on its own, however in the context of the study, it characterizes the urban driving habits of the users of BearOil app, on which actual FC is based.

3. Analysis

This study will attempt to provide reference for the claim that the FC gap is not negligible when attempting to pursue health and environmental goals at either the model and brand level, nor the national and urban levels. The analysis will simply compare passenger vehicle FC gap in several manners:

(i) ***General FC gap***: by transmission (AT/MT) and by-segment.

(ii) ***Weight and Technology configuration gap:*** weight-reduction FC impact and Turbo FC impact.

(iii) ***Spatial and Temporal gap***: Geely Boyue 2016 1.8TD AT Smart model was selected as a by-geography and by-season comparison model because of the relatively high volumes of respondent data.

(iv) ***By-model gap:*** brand FC gap assessment ideally holds driving conditions equal among drivers, yet in this simplified analysis driving habit and conditions are assumed insignificant.

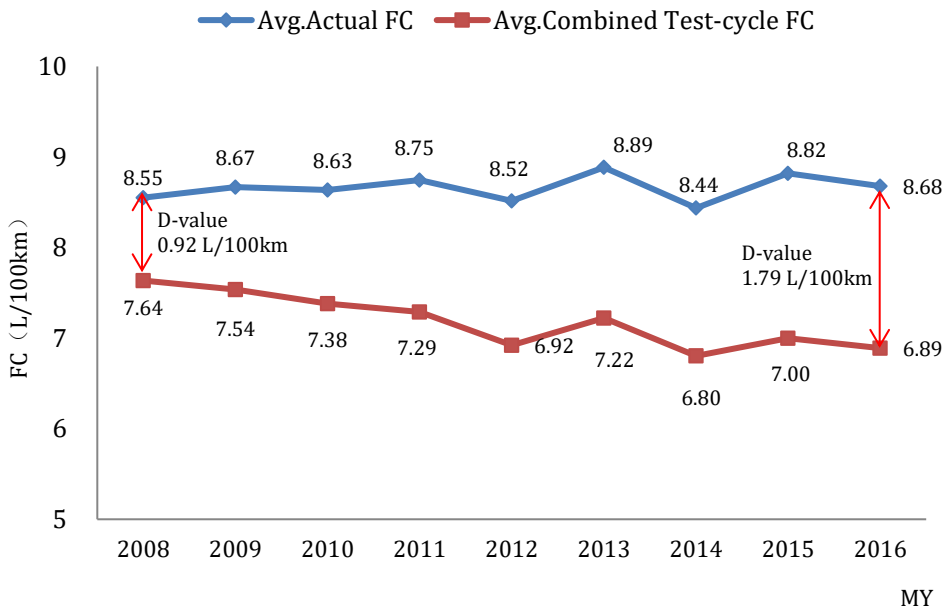
(v) ***Best-selling vehicles FC gap:*** 2016 top 100 selling cars FC gap analysis.

3.1 General FC gap

3.1.1 Reported and actual FC gap development trend

The reported and actual fuel consumption gap development trend reflects the effectiveness of the consumption standards in delivering real-world impacts. Figure 7 shows that the average actual fuel consumption (as reported by validated Xiaoxiong App users) increased from 8.55L/100km to 8.68L/100km, a revealed increase of 1.5% in eight years, while the reported FC (as posted in MIITs website, for the same vehicle models) decreased from 7.64L/100km to 6.89L/100km, a stated decrease of 9.8%. The gap increased from 0.92L/100km in 2008 to 1.79L/100km in 2016. Multiple reasons may have impacted the increase in gap, from changes in standard design, standard enforcement, driving conditions etc. An analysis of the impacting factors is beyond the scope of this work.

Figure 7: Reported and actual FC development trend comparison



Note: Actual FC is based on BearOil App data and reported FC is based on national reporting (MIIT's website).

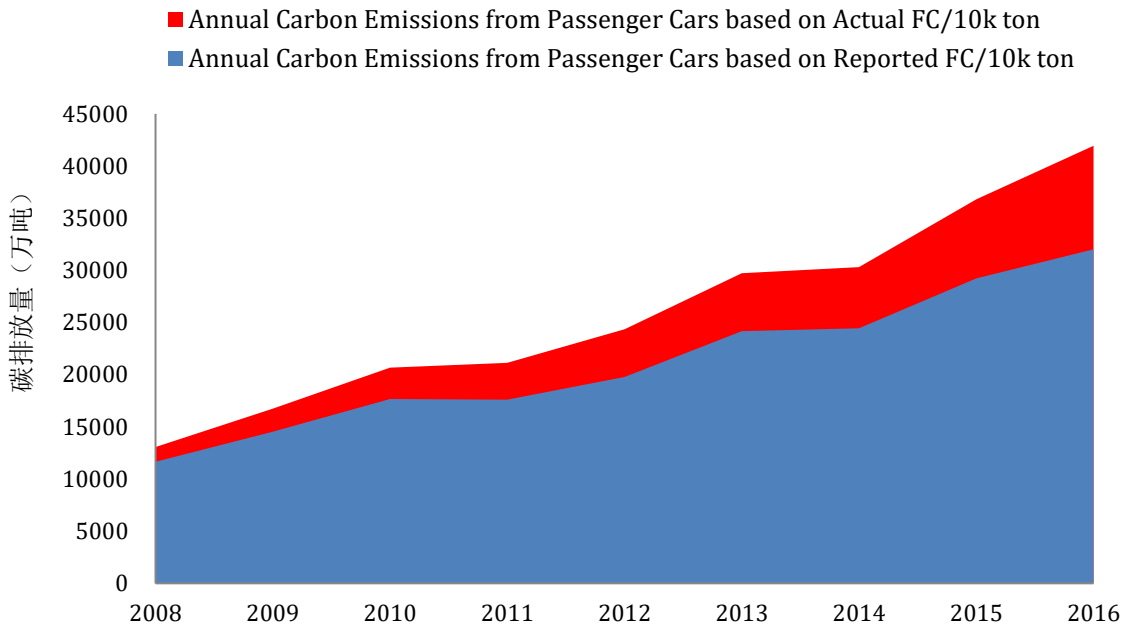
The impact of fuel consumption on China's carbon emissions, under the reported FC scenario and under the actual FC scenario, is reflected in Figure 8. The figure illustrates the importance of the FC standard regime the national effort to curb carbon emission. The following formula devised this calculation:

$$E_{\text{National}} = FC_{vehicle} \times M_{vehicle} \times \alpha_{petrol} \times T_{National} \quad (1)$$

Where, E_{National} refers to the national total carbon emissions of passenger cars; FC_{vehicle} refers to the

Average fuel consumption level of a passenger car; $M_{vehicle}$ refers to the average annual mileage of a car, assumed to be 13,000km; α_{petrol} refers to the gasoline carbon emission factor, assumed 2.361kg/L; $T_{National}$ refers to the national passenger car ownership volume.

Figure 8: Comparison between cumulated carbon emissions resulted from reported and actual FC



Note: Actual FC is based on BearOil App data and reported FC is based on national reporting (MIIT's website).

3.1.2 By-transmission type FC gap analysis results

The majority of vehicles sold and operated in China have automated transmissions. Automatic transmission (AT) vehicles accounted for 59.5% of vehicles sold in 2015 and have been steadily increasing their share of the market since 2012,[22] as illustrated in **Figure 9**.

Real-world FC data collected through the BearOil's app is represented by both AT and manual transmissions (MT) cars, with AT vehicles contributing to as much as 74.1% of the total data sample. Automated vehicles tend to have higher fuel consumption gaps than MT vehicles[23], and the difference between types of transmission has overall remained the same. The results of the study are slightly biased towards the larger FC gap of AT (versus MT), as represented in **Figure 10**. Therefore, we performed a correlation in order to prevent such bias using the following formula:

$$S_2 = S_{AT1} \times \alpha_{AT2} + S_{MT1} \times (1 - \alpha_{AT2})$$

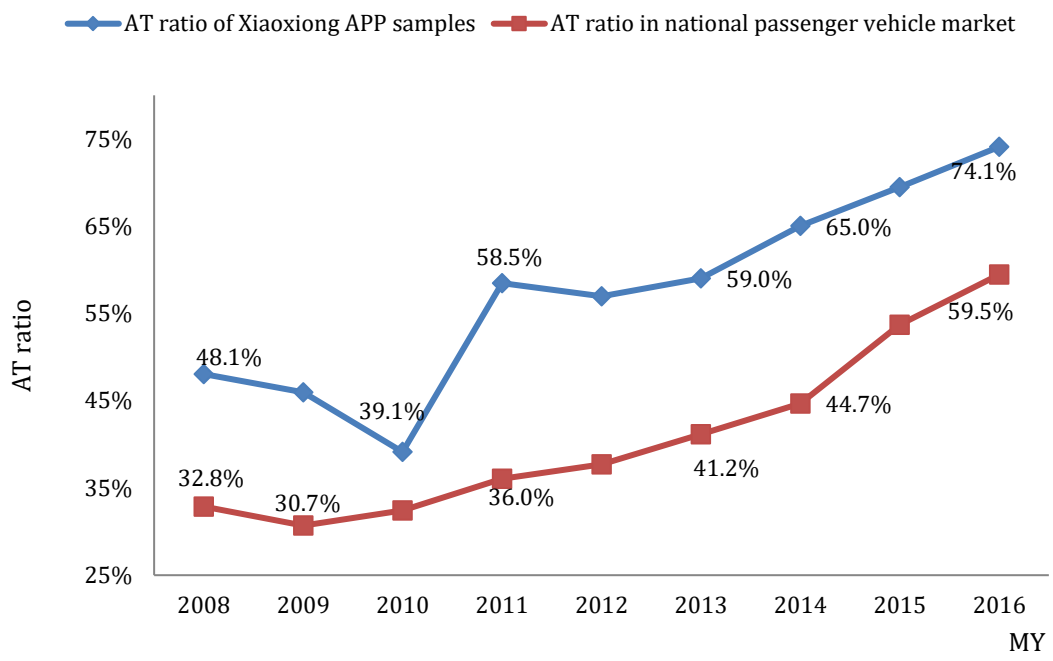
Where: S_{AT1} represents the AT FC gap, S_{MT1} represents the MT FC gap, and α_{AT2} represents the actual AT market portion.

[22] CAAM and CATARC, China Auto Development Annual Report. http://max.book118.com/html/2015/0725/21954233.shtm

[23] It is argued that technically, AMTs, CVTs, DCTs and multi-gear ATs are more energy-efficient and fuel-efficient than manual gear shafts, but the problem with automatic gear models is that companies are setting fuel consumption control strategies closer to the NEDC Working conditions, which in turn hamper the FC performance under actual driving conditions.

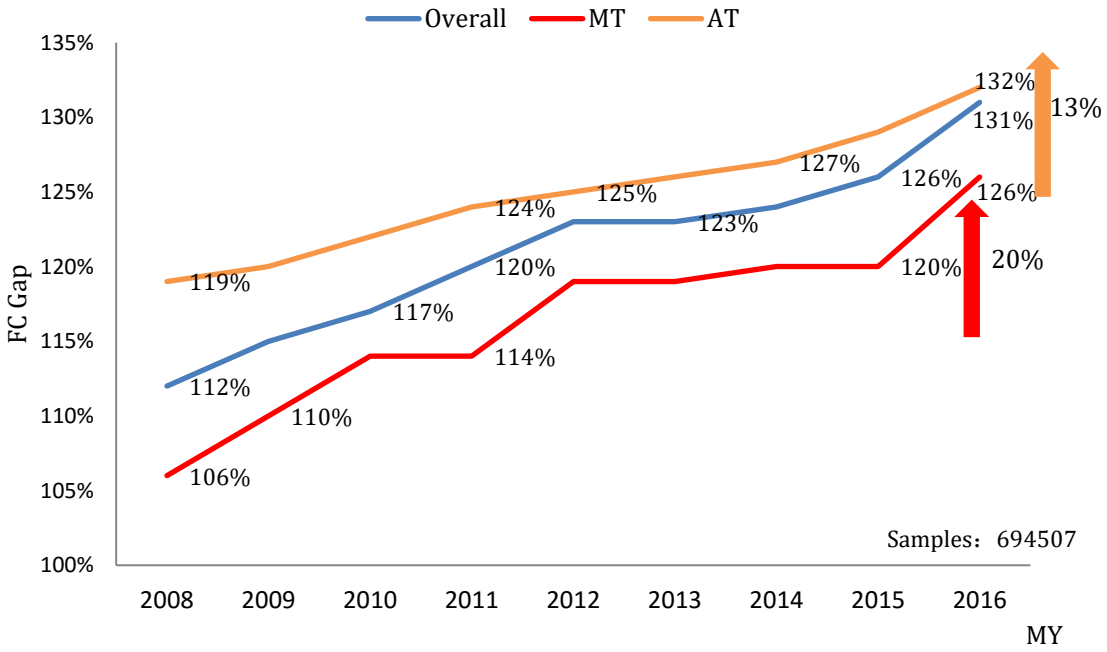
After the correction, the FC gap is slightly lower than that of the original data sample, as shown in Figure 11. However, as the proportion of AT increases over time, so will the FC gap.

Figure 9: The proportion of MT cars between 2008-2016



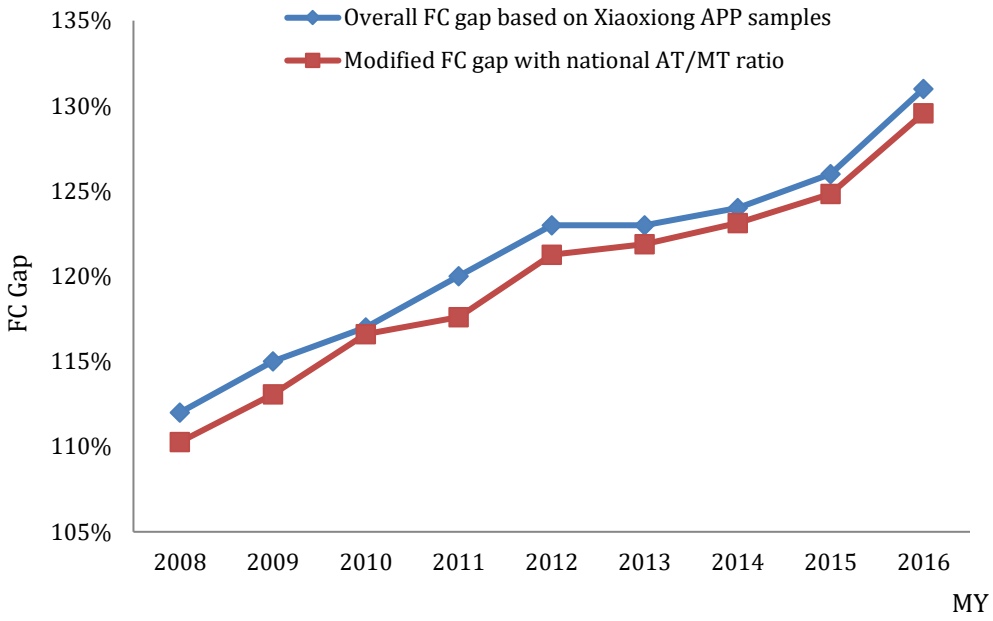
***Note**: AT/MT ratio data is retrieved from CATARC's China Auto Industry Development Annual Report.*[24]

Figure 10: China's 2008-2016 actual vs. reported FC



[24] http://max.book118.com/html/2015/0725/21954233.shtm

Figure 11: Corrected versus original FC gap



***Note**: The correlation formula enacted here used the FC gap and balances it using the market portion of ATs and MTs in China during 2016.*

3.1.3 By-segment FC gap analysis results

3.1.3.1 Overall analysis

Vehicles can generally be divided in accordance to their wheelbase, body style, and engine size. Here we use the following (SINA portal[25] based) six segments of which significant real-world FC reporting was retrieved: small (including mini), compact, medium, and large cars, SUVs, and MPVs. Because of smaller data volume and representation biases for the app's first two years (the app was released in 2008), this section focuses on data starting in 2010.

Presented in **Figure 10** and **Table 4**, the segmentation FC gap analysis demonstrates a few interesting points: (1) the large, MPV, and medium-sized vehicle segments have seen the smallest increase in FC gap over the past seven years (10% and below), (2) compact cars saw the largest increase over the past seven years, of 16%, (3) Sport Utility Vehicles (SUVs), which are seeing significant market growth in recent years in China, saw a steady increase in FC gap reaching 130%, (4) Multi-Purpose Vehicles (MPVs) achieved the smallest annual gap last year of 121%, (5) Besides MPVs, which maintained a constant FC gap, all car segments saw an average increase in their FC gap over the past year.

Table 4: By-segment FC gap development

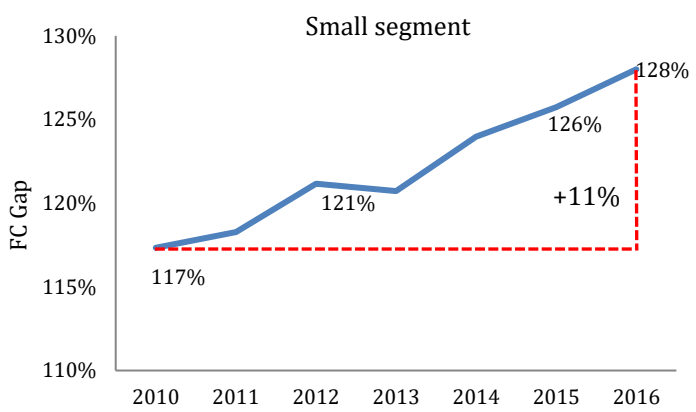
Year/ Segment	2010	2011	2012	2013	2014	2015	2016	Annual Average change	7 Year Cumulative gap
Small*	117%	118%	121%	121%	124%	126%	128%	1.6%	11%

[25] Sina Auto http://auto.sina.com.cn/

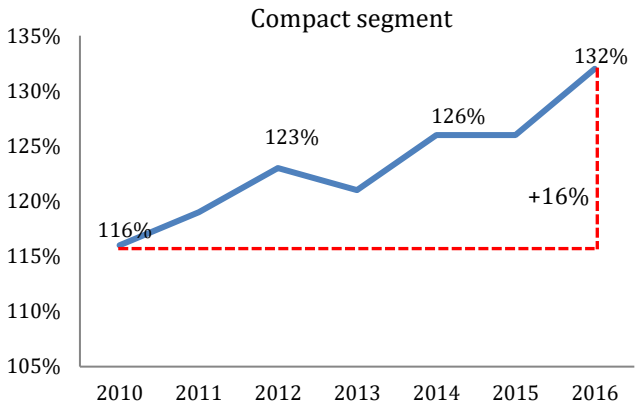
Compact	116%	119%	123%	121%	126%	126%	132%	2.3%	16%
Medium	120%	126%	122%	129%	125%	128%	130%	1.4%	10%
Large	128%	129%	136%	131%	132%	125%	131%	0.4%	3%
MPV	114%	117%	118%	118%	115%	121%	121%	1.0%	7%
SUV	118%	119%	124%	124%	122%	126%	130%	1.7%	12%

* Weighted average calculation includes both small and mini vehicles.

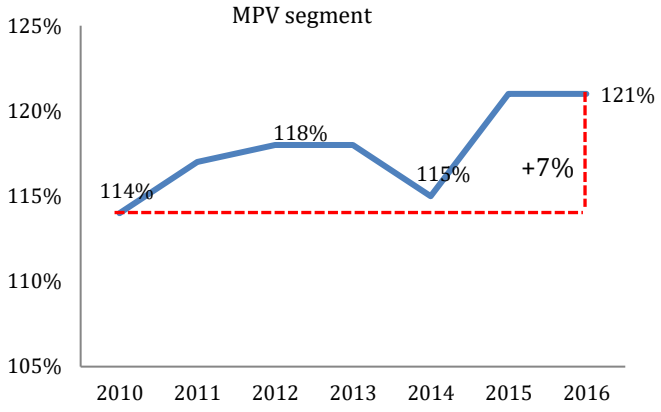
Figure 12: By-segment FC gap analysis results



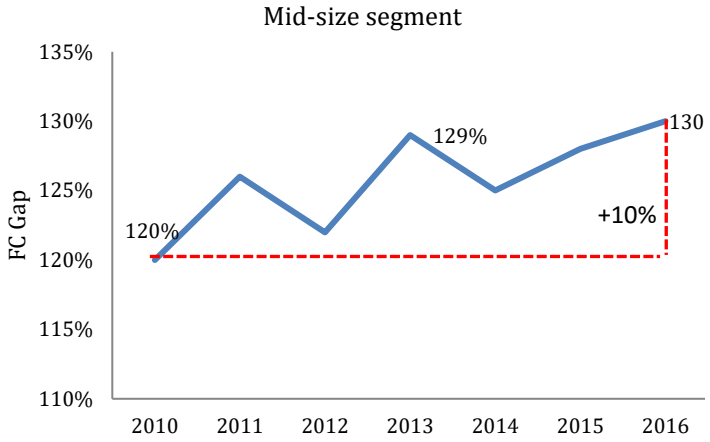
Sample size：81396
MY：2010-2016



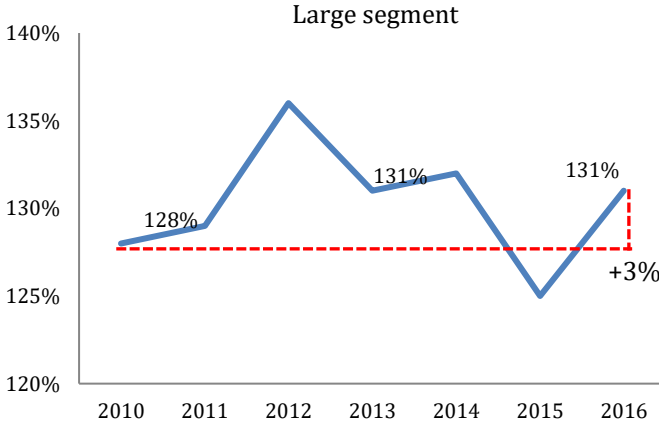
Sample size：301013
MY：2010-2016



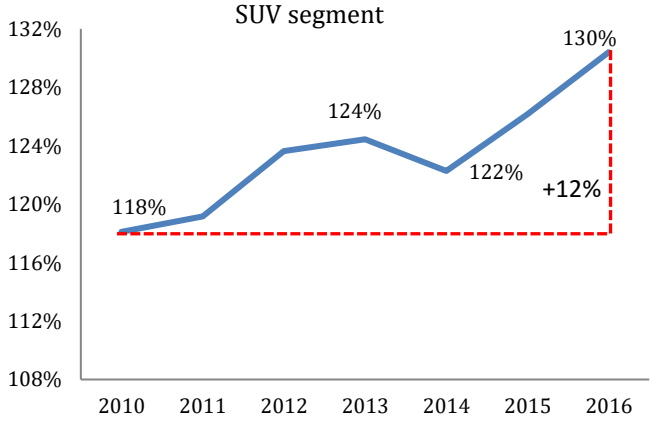
Sample size：10830
MY：2010-2016



Sample size：65560
MY：2010-2016



Sample size：2625
MY：2010-2016



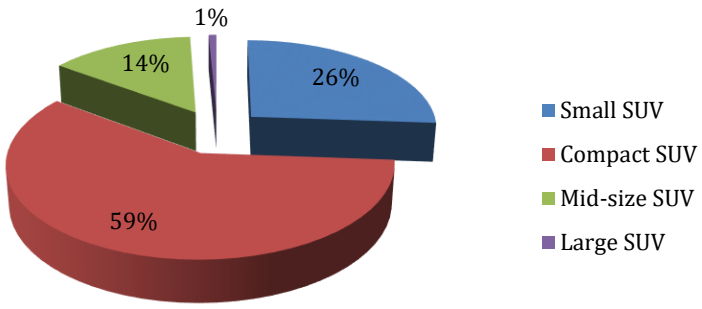
Sample size：182665
MY：2010-2016

3.1.3.2 SUV in-depth analysis

In 2016, the sales of SUVs reached 9.047 million, up 44.6% from the previous year, accounting for 37.1% of the total sales volume of passenger cars in China. To meet the needs of different user groups, SUV products are now more refined and divided into micro SUVs, compact SUVs, medium SUVs, mid-large SUVs, and large SUVs. Their FC level and actual FC performance also varies. Therefore, it is necessary to treat SUV analysis with caution, for instance by using its inherent subdivision.

Figure 11 shows that the current BearOil real-world FC data contains four subdivisions (it excludes the large SUV). The data is dominated by small SUVs and compact SUVs, while large SUVs account for only 1% of the total sample size. Therefore, the results of the SUV analysis in the previous section do not capture the FC gap trend accurately. Further detailed and careful analysis of FC gap of the SUV segment will be the focus of our next FC gap analysis.

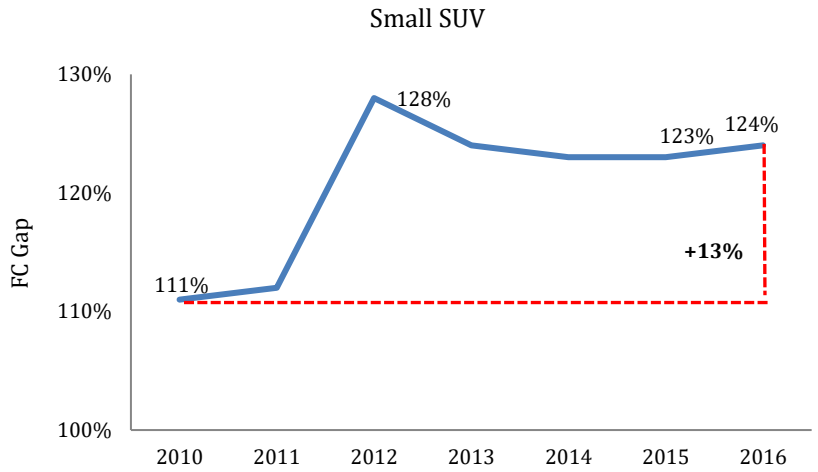
Figure 13: Sample proportions of different SUV types in BearOil database



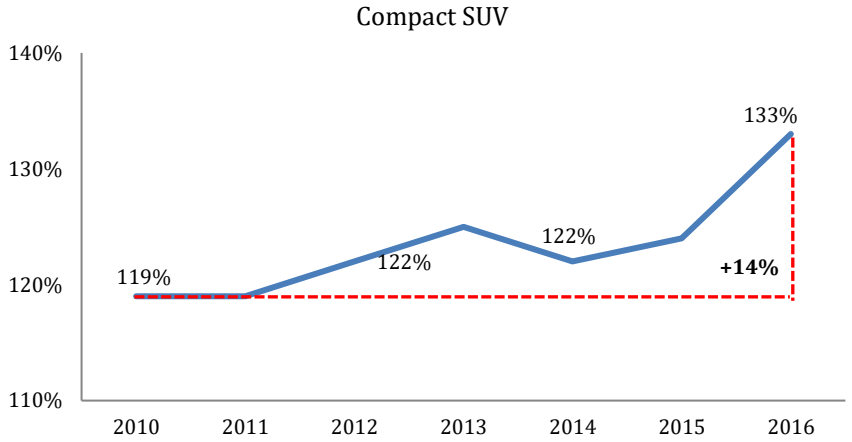
Sample Size: 186139
Model Year: 2008-2016

Figure 12 compares the FC gap trends of different SUV subdivisions and finds that, (1) the difference in fuel consumption between 2010-2016 compact SUV and small SUV is the largest, reaching 14% and 13%, respectively, pretty close to large SUV FC gap of 12%; and, (2) the compact SUV FC gap was the largest, at 133%, while small SUV FC gap was the smallest, at only 124%. It is worth noting that given the relatively small data sample of large and small SUVs, this simplistic comparison may have representation problems.

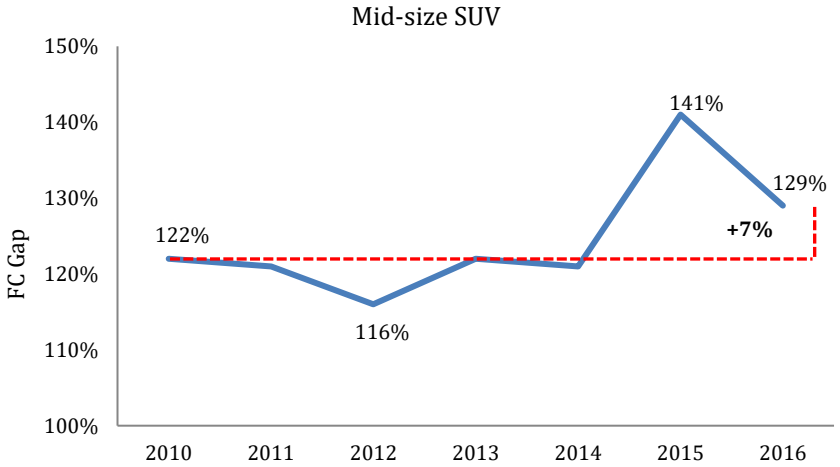
Figure 14: SUV in-depth analyses results



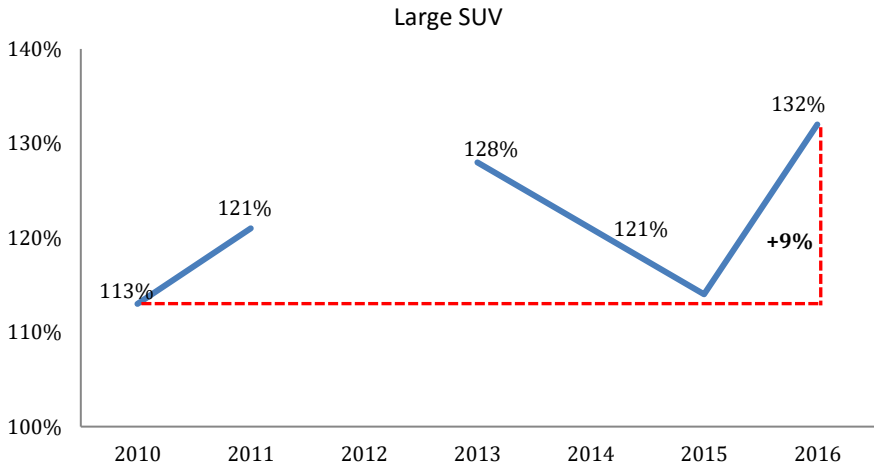
Sample size：47447
MY：2010-2016



Sample size：108046
MY：2010-2016



Sample size：25811
MY：2010-2016



Sample size：1361
MY：2010-2016

3.2 Weight and technology impacts on China's FC gap

It is not news that vehicle curb weight and power train technology can impact FC performance. Weight is a major factor that has been widely studied in recent years,[26] while various technologies have been studied over the past couple of decades.[27] This section is aimed at assessing some of these impacts for in China.

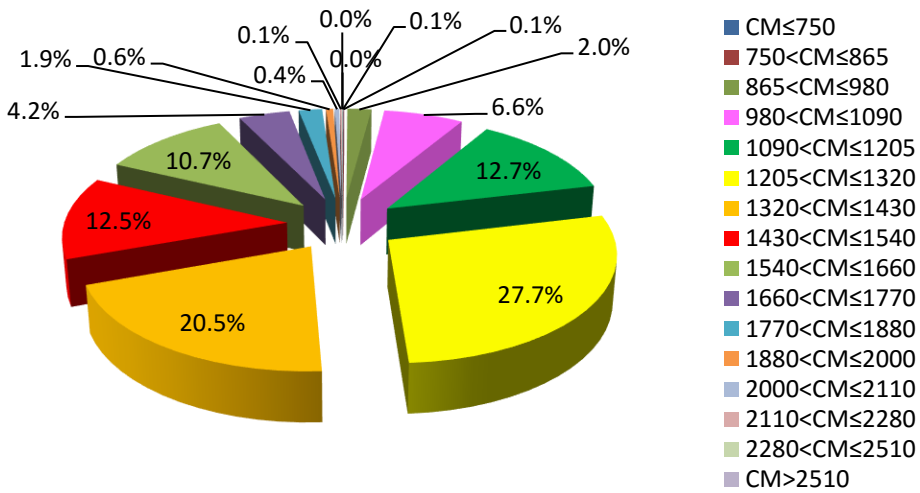
3.2.1 By-weight FC gap analysis results

China's current fuel consumption limits and target regulations are based on 16 vehicle weight-bins, the greater the weight, the higher the FC (and the lower the regulation demands). This approach does not favor the lightening of vehicles, making the regulation weight-based design worth examination.[28] Figure 15 shows the distribution of BearOil vehicle data by weight bins. Vehicles with weights ranging 1090kg to 1660kg account for some 84% of the sample, rendering the analysis for this weight range more reliable.

As shown in

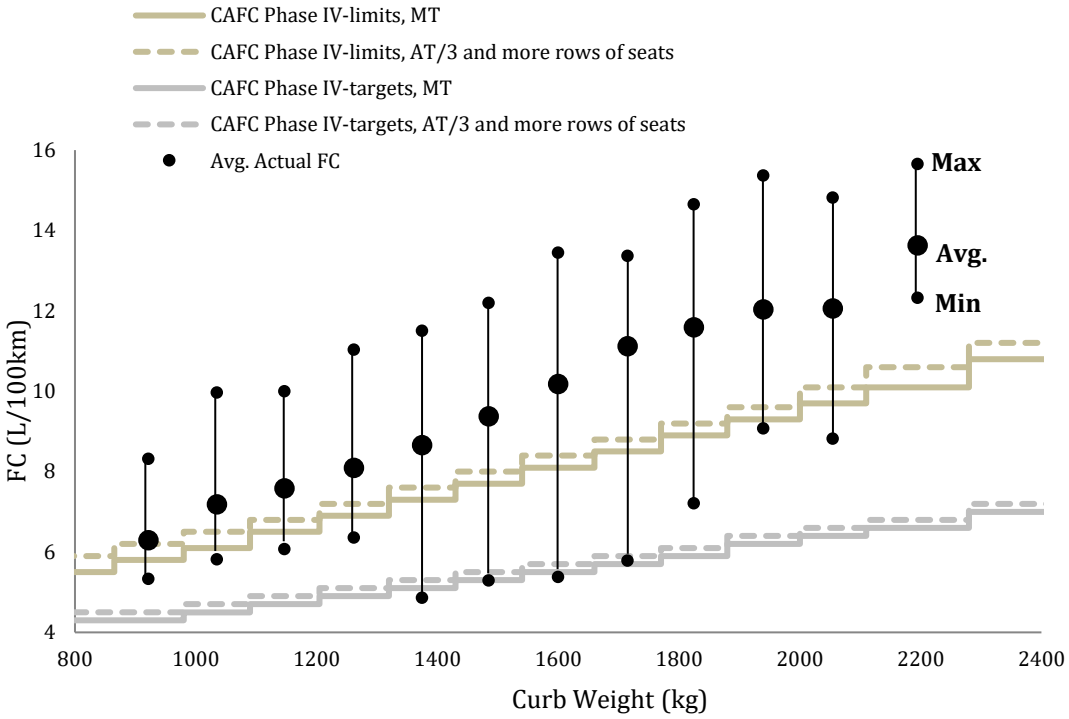
Figure 16, three interesting observations can be made: (1) For any weight group, actual FC is higher than the reported FC and even higher than the limit; (2) For models with curb weight lower than 1200kg or at the range of 2110kg-2280kg, the FC gap tends to be the smallest; (3) Models with curb weight ranged from 1660kg-1770kg typically have the largest FC gap, and the gap fluctuation is also the largest (e.g. Mercedes- BMW 5 Series, Audi A6, Haval H5, Volkswagen Tiguan SUV models).

Figure 15: By-weight vehicle portion of China's passenger fleet (BearOil database)



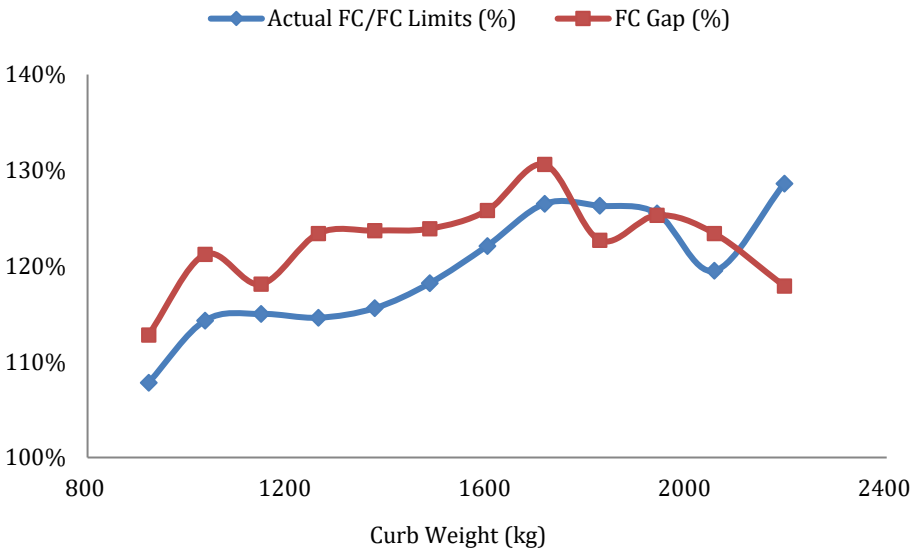
[26] For example: https://pdfs.semanticscholar.org/c3df/aac9ee16b48f5555028e71a7ed0b593c3010.pdf
[27] For example: http://papers.sae.org/2016-01-0905/
[28] ICE vehicle energy efficiency improvements should be highlighted along with NEV in pursuit of CAFC target. *iCET* (2017-08-07) http://www.icet.org.cn/news.asp?id=376

Figure 16: Vehicle curb-weight based actual FC versus FC limit



Note: *Weight ranges with less than total 900 samples and less than five models are excluded in the analysis.*

Figure 17：Vehicle curb-weight based FC gap analysis

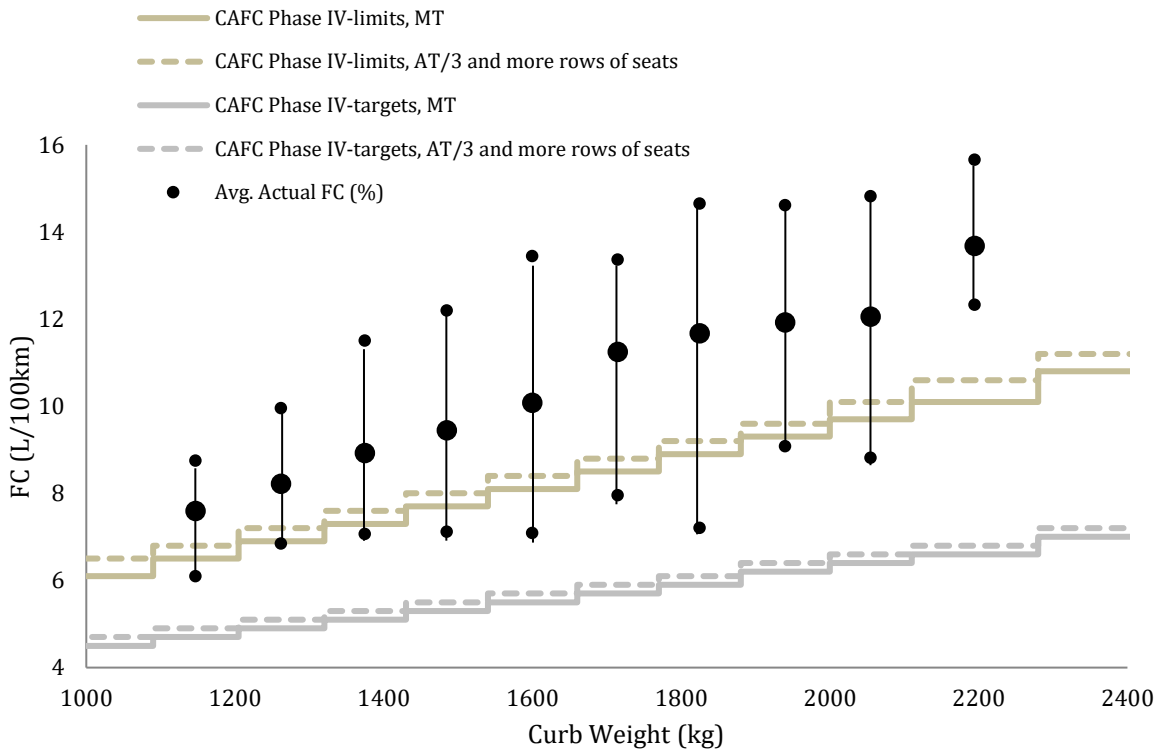


Note: *Weight ranges with less than total 900 samples and less than five models are excluded in the analysis.*

The same method was used to examine SUV models (**Figure 18**/17). It was found that: (1) there was no SUV distribution within mass range of 980kg or less, and SUVs were largely concentrated in the range of 1320kg to 1770kg – a relatively higher curb weight (not shown in the figure); (2) In any mass

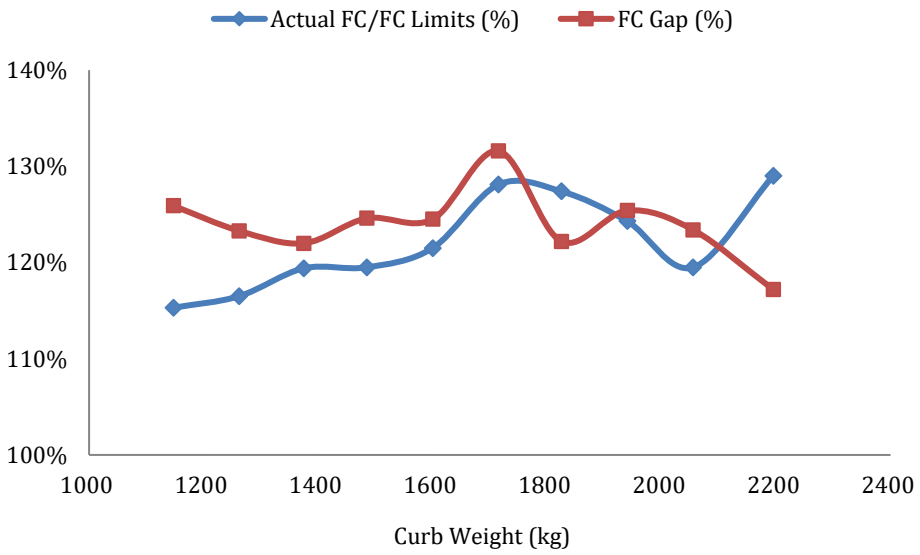
range, the actual average FC of the sample vehicle models was higher than the standard limits for the corresponding weight bin, of which the 1090kg to 1205kg range saw the lowest FC gap; and, (3) lighter weight SUVs tend to be concentrated around an average FC gap, and are less likely to fluctuate.

Figure 18: Vehicle curb-weight based actual FC versus FC limit for SUVs



Note: *Weight ranges with less than total 890 samples and less than 5 models are excluded in analysis.*

Figure 19: Vehicle curb-weight based FC gap analysis for SUVs

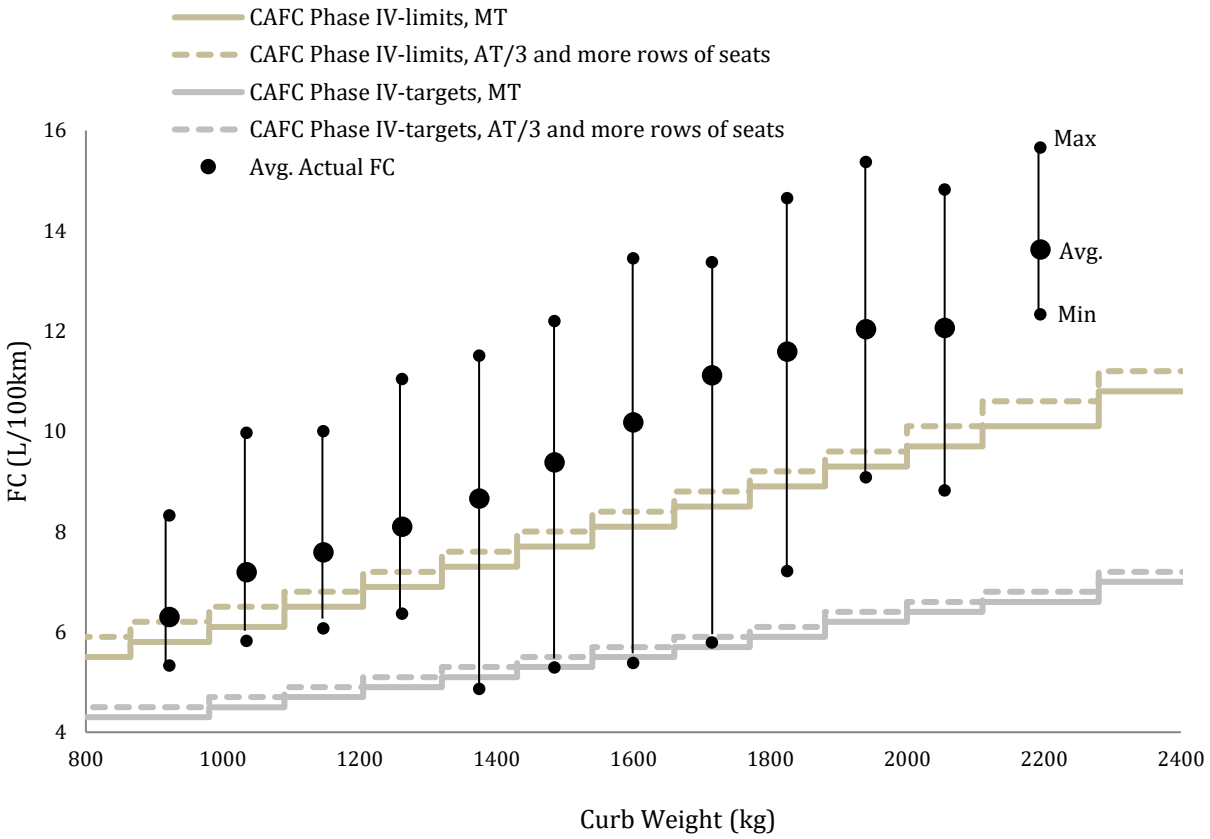


Note: *Weight ranges with less than total 890 samples and less than five models are excluded in analysis.*

MPV FC gap analysis is presented in **Figure 20**, demonstrating that: (1) The six weight bins had a

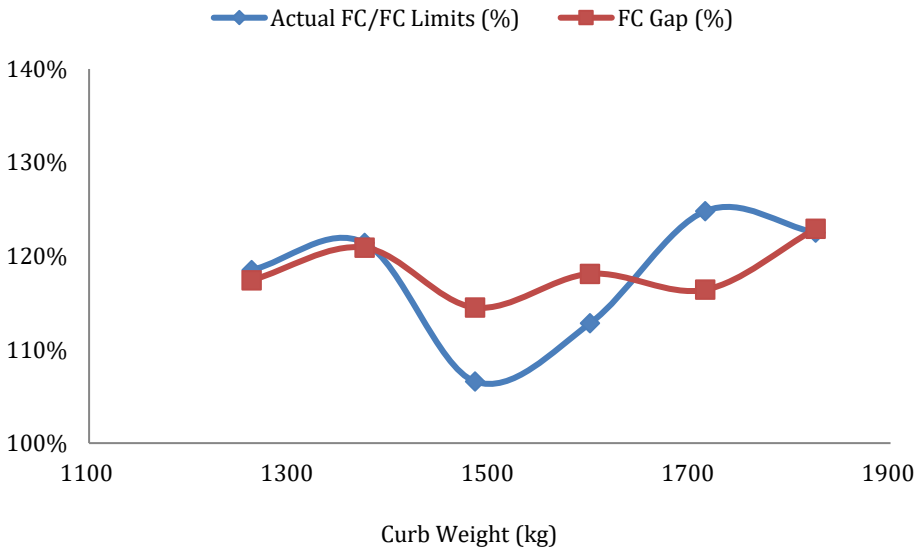
sample size containing at least five models with over 800 data inputs; 2) The actual FC and FC limit values of the models in the mass range of 1430kg to 1540kg (41% of the input data) was the lowest, averaging 106.6%.

Figure 20: Vehicle curb-weight based actual FC versus FC limit for MPVs



***Note**: Weight ranges with actual FC sample size smaller than 900 and less than 5 vehicle models are excluded from the analysis.*

Figure 21: Vehicle curb-weight based FC gap analysis for MPVs



***Note**: Weight ranges with actual FC sample size smaller than 900 and less than 5 vehicle models are excluded from the analysis.*

3.2.2 A typical actual FC range for a certified range

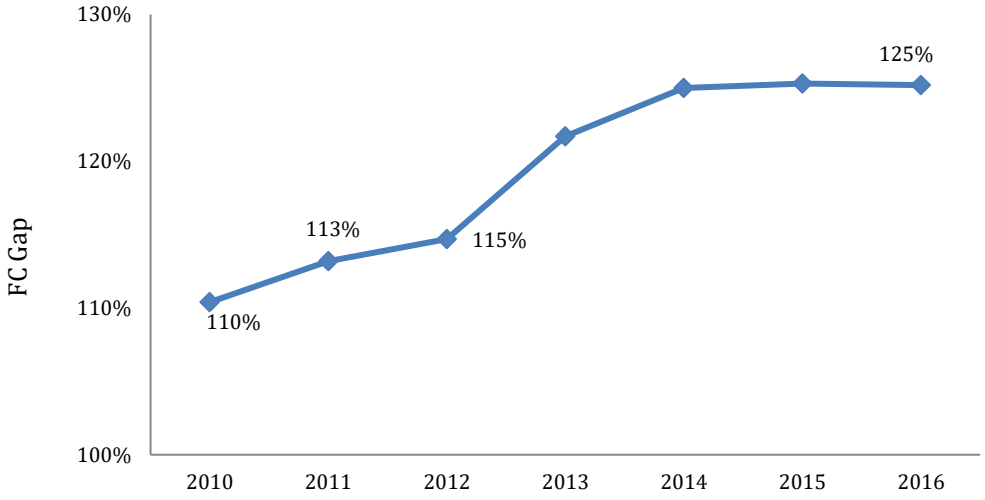
2016 is the first implementation year of Phase IV of China's passenger cars FC standard. Due to the scaling of vehicle weigh in recent years, it may be useful to understand the reported versus actual FC gap for heavier vehicle weight-bins. We therefore selected the following typical FC rates: 6.9L/100km, which is China's average FC target for 2015, 7.9L/100km, 8.4L/100km, and 8.8L/100km.

Table 5: China's CAFE Phase IV standard; by-weight FC limits and targets for MY2016

Curb Mass (CM) (kg)	Phase IV Limits		*Phase IV Targets*	
	MT and/or <3 seat rows	AT and/or >= 3 seat row	*3 seat row and cw <= 1090kg*	*3 seat rows and cw> 1090kg or > 3 seat rows*
CM≤750	5.2	5.6	4.3	4.5
750<CM≤865	5.5	5.9	4.3	4.5
865<CM≤980	5.8	6.2	4.3	4.5
980<CM≤1090	6.1	6.5	4.5	4.7
1090<CM≤1205	6.5	6.8	4.7	4.9
1205<CM≤1320	6.9	7.2	4.9	5.1
1320<CM≤1430	7.3	7.6	5.1	5.3
1430<CM≤1540	7.7	8.0	5.3	5.5
1540<CM≤1660	8.1	8.4	5.5	5.7
1660<CM≤1770	8.5	8.8	5.7	5.9
1770<CM≤1880	8.9	9.2	5.9	6.1
1880<CM≤2000	9.3	9.6	6.2	6.4
2000<CM≤2110	9.7	10.1	6.4	6.6
2110<CM≤2280	10.1	10.6	6.6	6.8
2280<CM≤2510	10.8	11.2	7.0	7.2
2510<CM	11.5	11.9	7.3	7.5

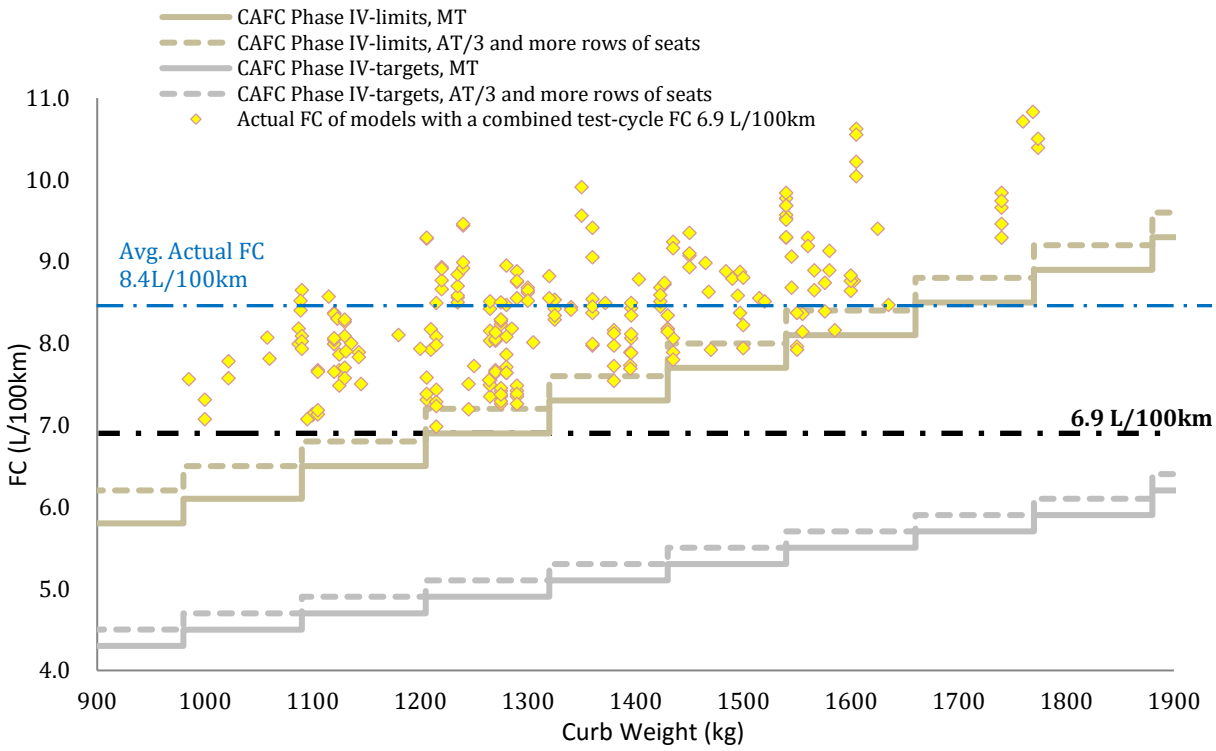
Demonstrated in **Figure 22**, the sample of cars that were certified 6.9L/100km saw a gradual increase in its FC gap beginning in 2010, reaching an actual FC of 125.2% than what is stated on their label. The curb weight of vehicles for which actual FC data was retrieved is concentrated in the range of 950kg-1800kg although cars weighting 1090kg-1320kg are required to meet the 6.9L/100km FC limit, and the majority of reported 6.9L were facing more relaxed FC limits. However, as demonstrated in **Figure 23**, the results show that the majority of 6.9L reported cars did not even meet their own (more relaxed) FC limit. Also, vehicles weighing between 950kg and 1100kg typically had FC gap of 103%-125%, while vehicles weighing 1700kg-1800kg had FC gaps ranging from 134%-155%. This implies that vehicle light weighting development could have an important positive impact on actual fuel consumption and emissions performance. The average actual FC was 8.4L/100km, some 21.7% above the reported 6.9 L/100km.

Figure 22: FC gap for sample vehicles certified 6.9L/100km, 2010-2016



Sample size：30079
Model Year：2010-2016

Figure 23: FC gap for the sample vehicles certified 6.9L/100km



***Note**: Each yellow rhombus in the figure represents a vehicle model.*

Demonstrated in **Figure 24**, the sample of cars that were certified 7.9L/100km saw an overall increase of more than 15% in the FC gap over the past eight years, with fluctuations, reaching a reported-versus-actual FC gap of 127.2% in 2016. The curb weight of vehicles for which actual FC data

was retrieved is concentrated in the range of 1100kg-1950kg although cars weighting 1430kg-1540kg are required to meet the 7.9L/100km FC limit. As demonstrated in

Figure 25, the majority of 7.9L reported cars did not achieve this FC under real-world conditions, and none of them met their required FC limit. The average actual FC was 10L/100km, some 26.6% above the reported 7.9L/100km.

Figure 24: FC gap for sample vehicles certified 7.9L/100km, 2008-2016

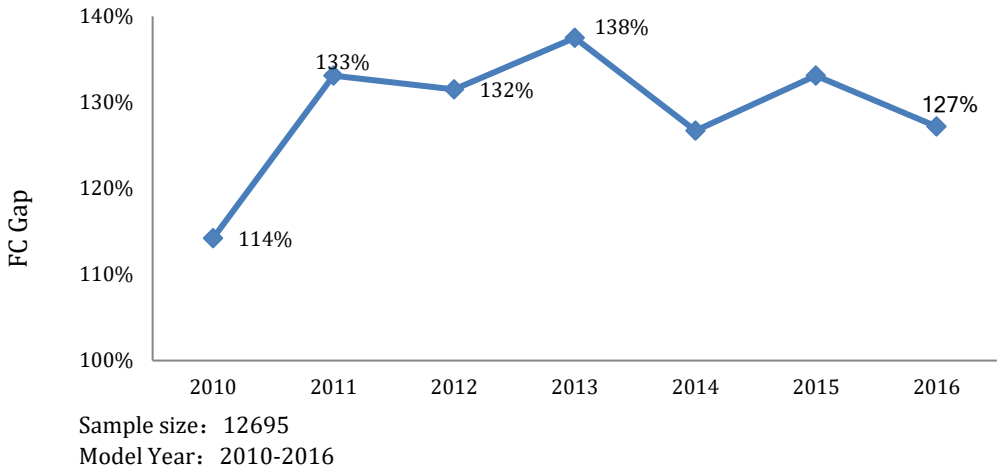
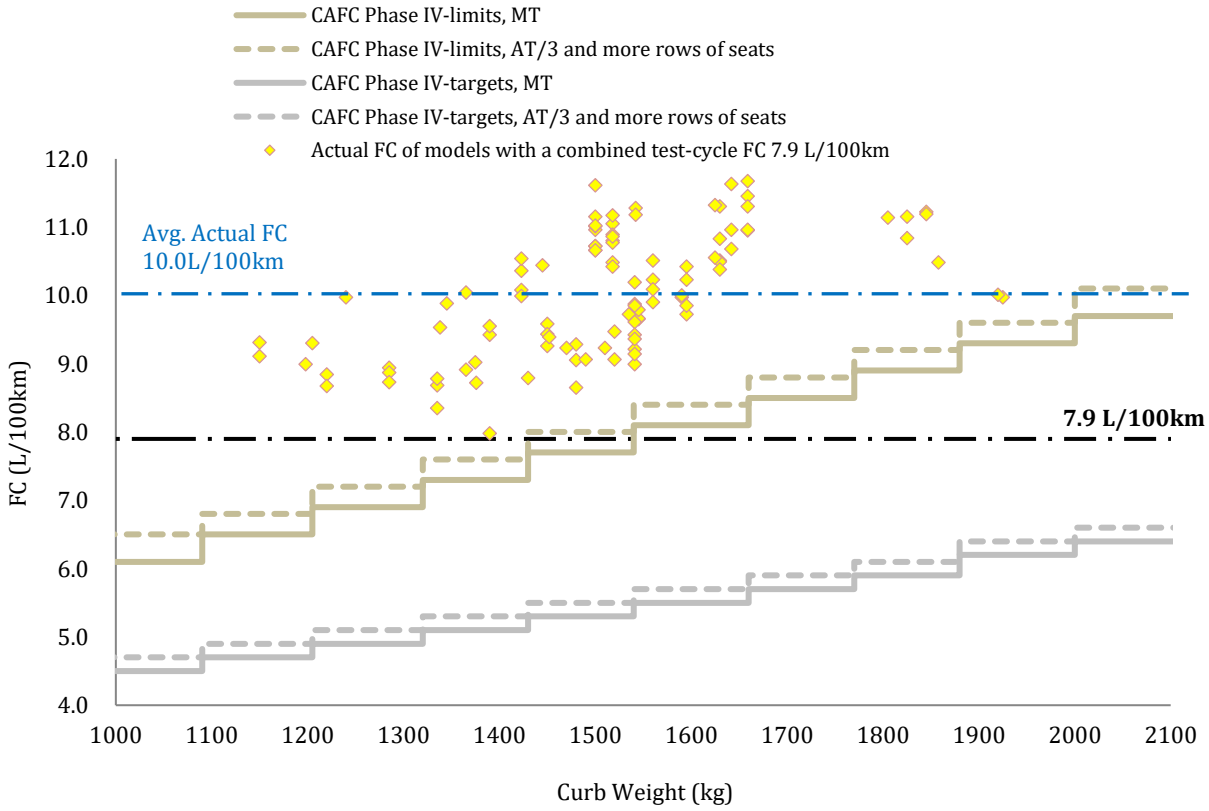


Figure 25: FC gap for the sample vehicles certified 7.9L/100km



***Note**: Each yellow rhombus in the figure represents a vehicle model.*

Demonstrated in **Figure 26**, the sample of cars that were certified 8.4L/100km saw an overall increase of over 12.4% in the FC gap over the past eight years, reaching a reported-versus-actual FC gap of 124.4% in 2016. The curb weight of vehicles for which actual FC data was retrieved is concentrated around the range of 1300kg-1950kg although cars weighting 1575kg are required to meet the 8.4L/100km FC limit. As demonstrated in

Figure 27, a majority of 8.4L reported cars in the sample did not achieve this FC under real-world conditions (one did, and a few came close). Some had a gap as high as 156%. Almost none of the sampled cars met their required FC limit. The average actual FC was 10.2 L/100km, some 21.4% above the reported 8.4L/100km.

Figure 26: FC gap for the sample vehicles certified 8.4L/100km

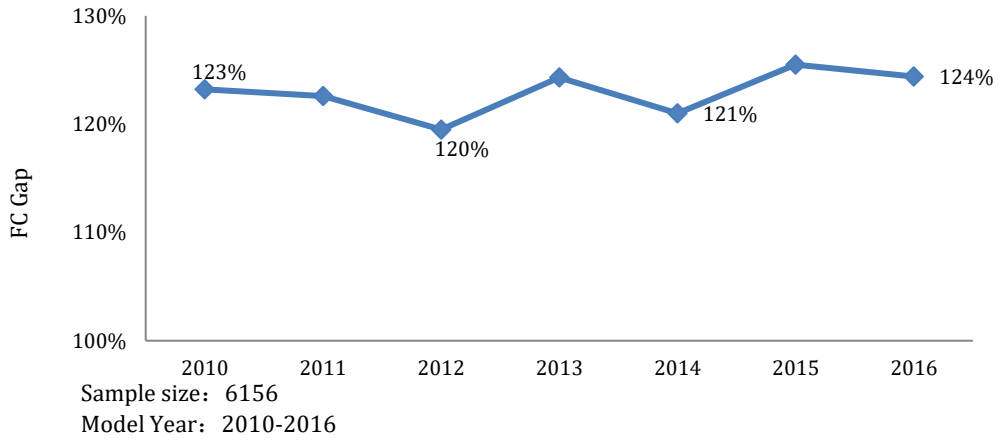
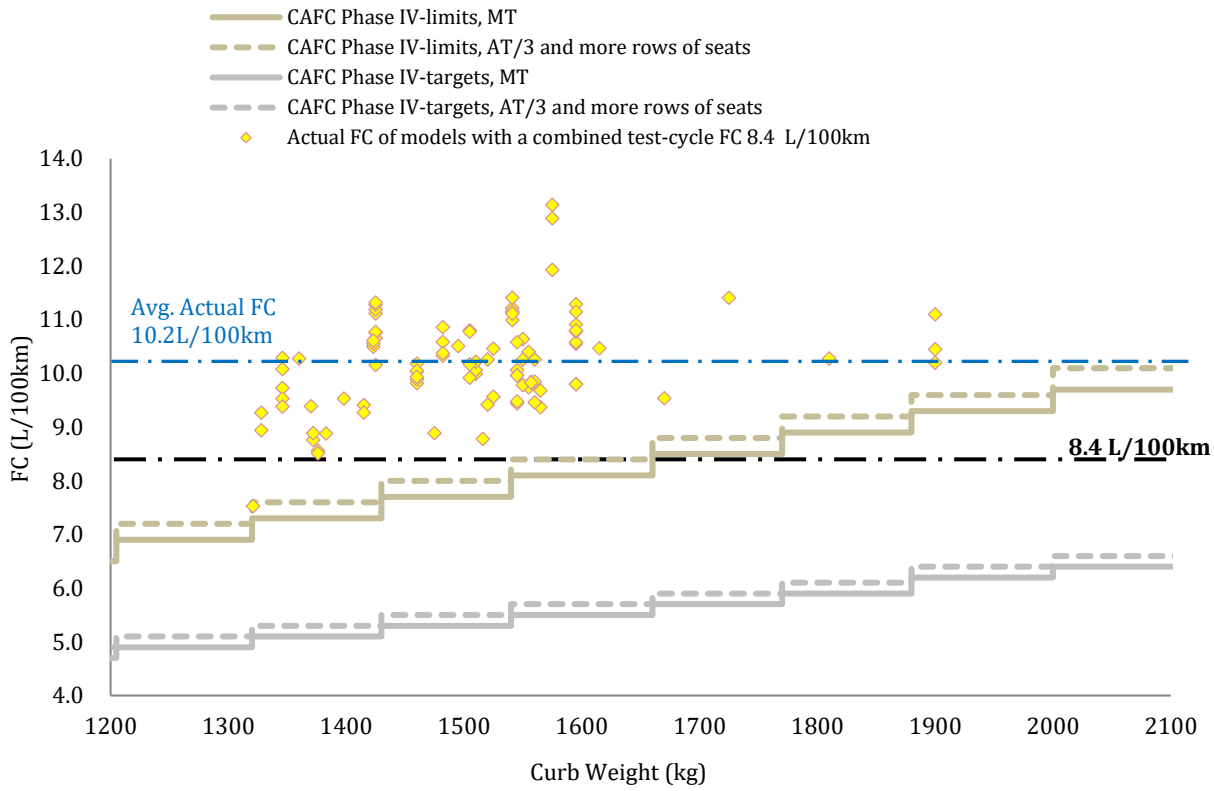


Figure 27: FC gap for the sample vehicles certified 8.4L/100km



***Note**: Each yellow rhombus in the figure represents a vehicle model.*

Demonstrated in **Figure 28**, the sample of cars that were certified 8.8L/100km saw an overall decrease of about 7% in its FC gap over the past eight years, reaching a reported-versus-actual FC gap of 123.8% in 2016. The curb weight of vehicles for which actual FC data was retrieved is concentrated around the range of 1400kg-1850kg, very similar to that of 8.4L/100km FC reported vehicles, although cars weighting 1770kg-1850kg are required to meet the 8.8L/100km FC limit. As demonstrated in **Figure 29**, a majority of 8.4L reported cars in the sample did not achieve this FC under real-world conditions (only one did). Some had a gap as high as 144%. None of the sampled cars met their required FC limit. The average actual FC was 11L/100km, some 25% above the reported 8.8L/100km.

Figure 28: FC gap for the sample vehicles certified 8.8L/100km

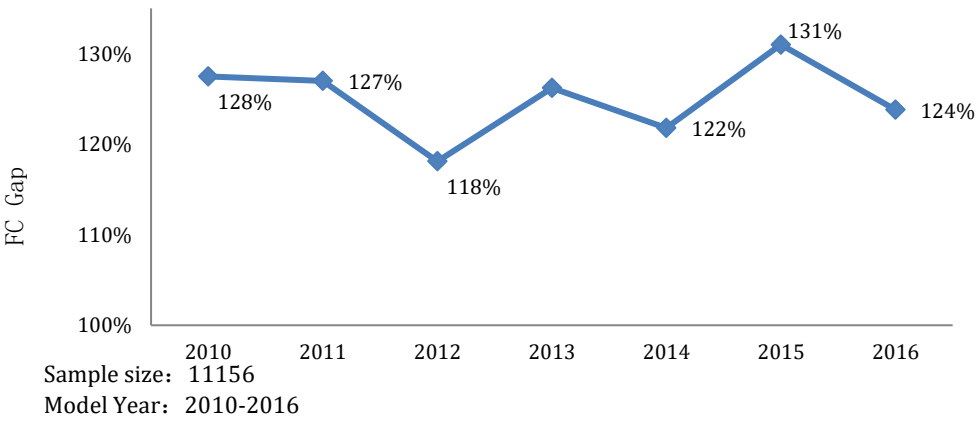
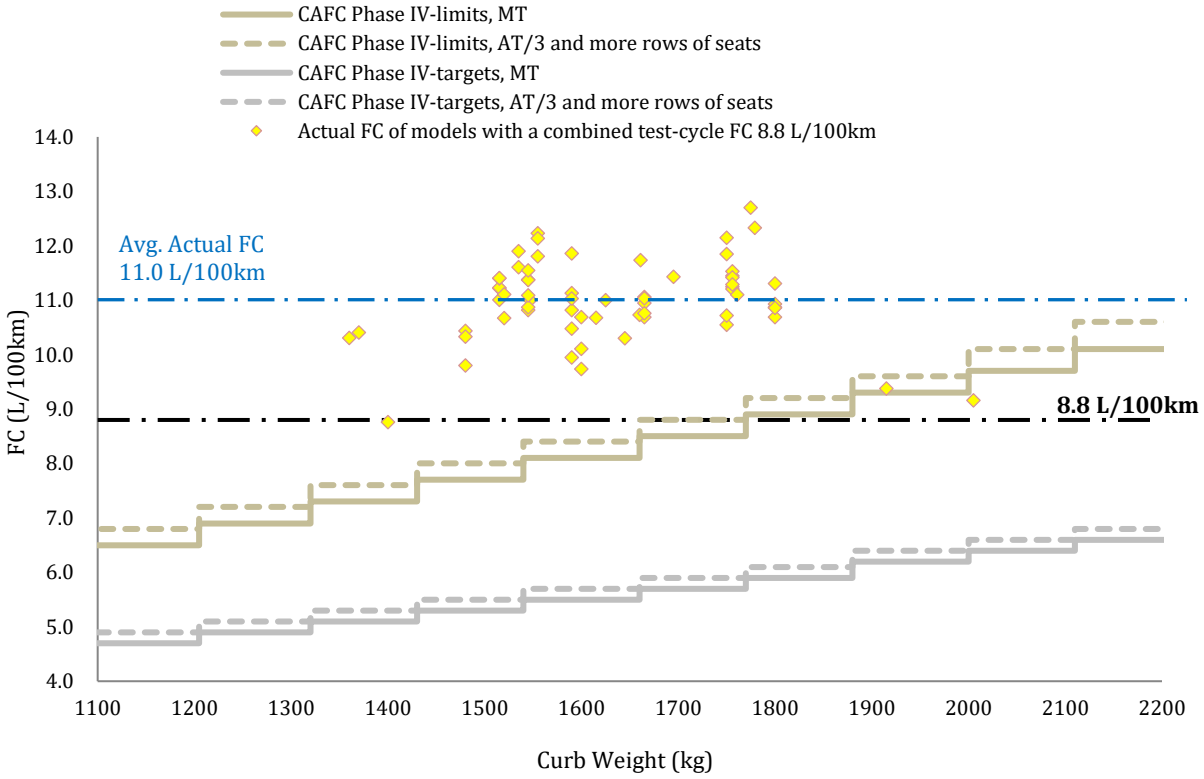


Figure 29: FC gap for the sample vehicles certified 8.8L/100km



***Note**: Each yellow rhombus in the figure represents a vehicle model.*

3.2.3 Turbocharging efficiency technologies' impact on the FC gap

Typical automotive fuel-saving technologies include hybrid vehicle technologies, more efficient gasoline engines and diesel technology (e.g. direct injection, turbocharging, variable valve timing technology, etc.), and lightweight vehicle technology.[29] This section will attempt to assess the impact of turbocharging technology on actual FC performance, acting as a feasibility study for the technology impact assessment through novel data source utilization.

A turbocharger is an induction device meant to force additional air into the combustion chamber of vehicle engine (increasing engine intake) in order to achieve higher engine efficiency and power output per unit of fuel consumed. A turbocharger is said to typically improve performance by 40%,[30] so that a 1.4T turbocharged engine car reaches the same power output as that with a 1.8L naturally aspirated engine.[31] The current NEDC FC test in China is more suitable for small-displacement supercharged engines. Such engines can achieve better fuel economy when tested, while naturally aspirated engines are at a disadvantage. Therefore, it is necessary to study the impact of turbocharger technology on the fuel consumption rate of different vehicles. Since the vehicle transmission greatly impacts engine load, it is important to distinguish between AT and MT when comparing TC performance.

The sample in this analysis was divided into four categories, that is, (a) MT-NA (naturally aspirated), (b) MT-TC (turbocharged), (c) AT-NA, and (d) AT-TC. Six models were selected for this analysis, after evaluating the data sample and requiring that the following criteria be met: (1) The

[29] A quick look at the difference between naturally aspirated and turbocharged engines, Auto Influence（2017-10-16）. http://www.autoinfluence.com/quick-look-difference-naturally-aspirated-turbocharged-engines/

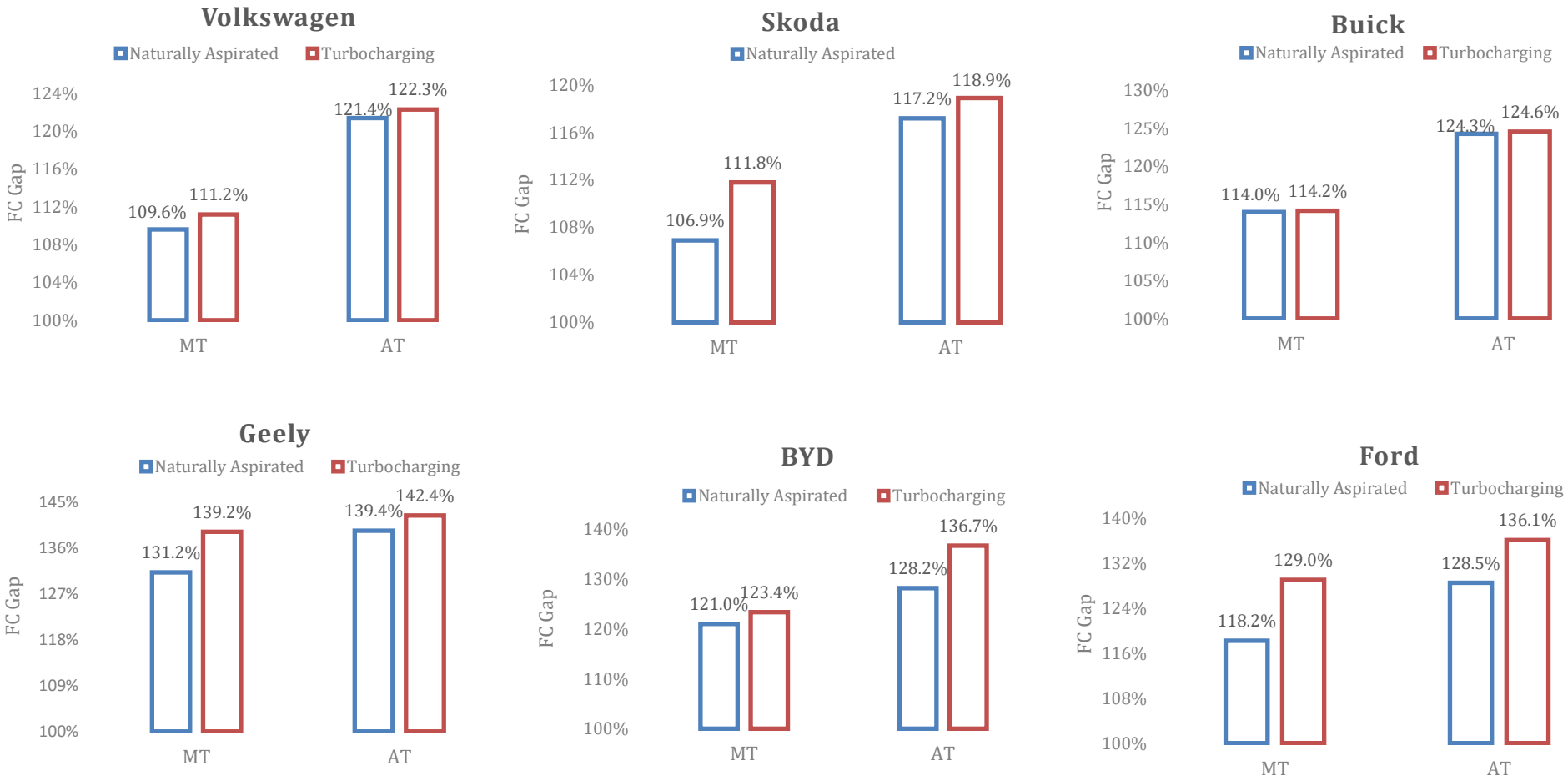
[30] For example: http://papers.sae.org/2016-01-0905/

[31] Difference between 1.4 L and 1.4 T，AutoHome: http://www.autohome.com.cn/dealer/201604/56143056.html

brand manual and automatic model category contains at least four turbocharged and naturally aspirated models; (2) the respective sample size of the above-mentioned four types (a, b, c, and d) have input from at least 500 cars. The total sample size of selected six brands reached 151,883.

Figure 30 shows that, (1) the FC gap of turbocharged vehicles is higher than that of the naturally aspirated model of the same transmission type. The most significant gap was reached by the Ford MT model with a difference of 10.8%; (2) the FC gap of MT models (including both turbocharged and naturally aspirated) was overall lower than that of AT models, information consistent with previous research.

Figure 30: Turbocharger FC gap impact in selected brands



3.3 Spatial and temporal FC gap analyses results

In order to compare FC gaps during different seasons and at different locations within China, this year we chose to focus on the Geely Boyue 2016 models 1.8TD automatic transmission model, a popular vehicle that sold over 100,000 units in 2016. The average FC of the selected model is 7.8L/100km.

Figure 31: Specifications of selected model

Model Name：Geely Boyue
Engine size：1.8 L
Segment：Compact SUV
Curb Weight：1670kg
Combined FC：7.8 L/100km
MSRP：￥148.8k

3.3.1 Spatial FC gap analyses results

The BearOil app added a by-geography feature to its list of data analysis capabilities in 2014 called the Fuel Consumption Index (FCI).[32] This new feature enables a snapshot of fuel consumption levels for a particular vehicle model at different locations, indicating the by-geography condition impacts on FC differentiation or driving style "areas" (assuming driving conditions for the compared location are similar).

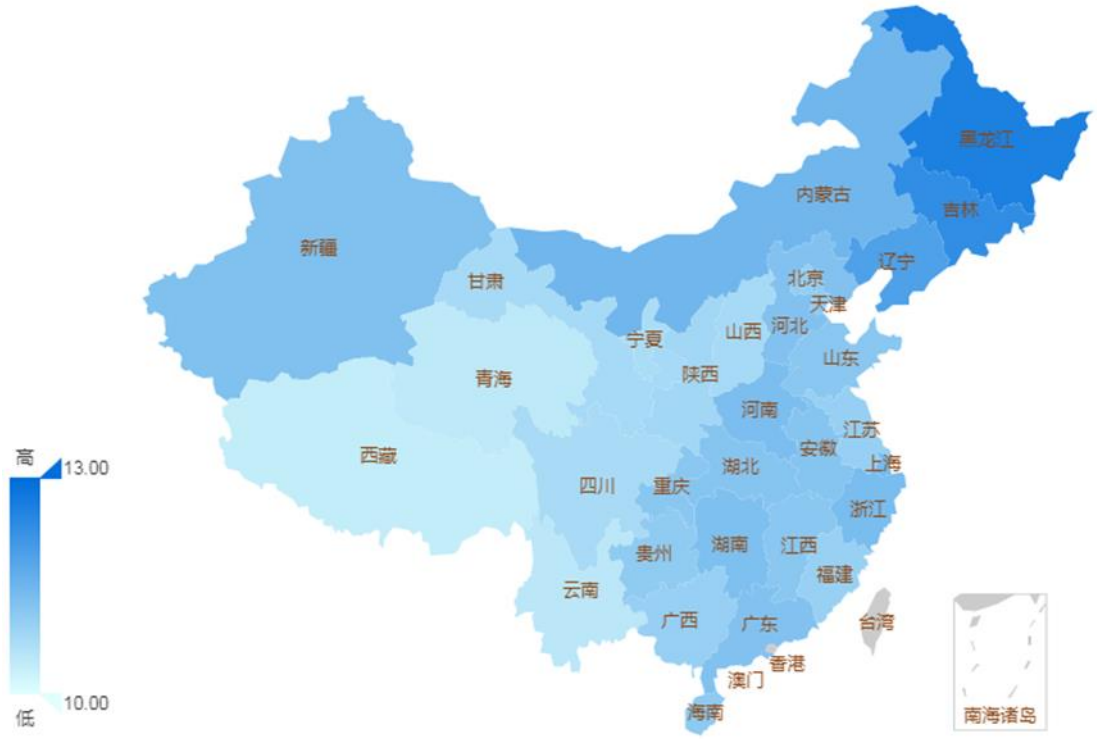
This section enables, (1) an overview of a single model real-world FC compared with the total average and certified FC, and (2) a comparison of by-province FC variations throughout the year (see Figure 30). The former demonstrates the high volatility in FC levels for the same car if driven in different provinces, shedding light on the discrepancies in external driving conditions within each province. The latter demonstrates the annual variations in FC arguably impacted by various external sources.

The data of the selected model provided from 31 provinces, cities, and regions (excluding Hong Kong, Macao, and Taiwan), was compiled in **Figure 32** to show gap differences. The deeper the blue color, the wider the FC gap and vice versa. It can be seen clearly from the map that the average actual FC of the model in any area is above 10L/100 km, well above the reported 7.8L/100km. The average actual FC reached is 11.15L/100 km, representing a 143% gap from its official reported FC.

[32] FCI Map. *Xiaoxiong APP*. http://www.xiaoxiongyouhao.com/dashboard/FCImap.php

In general, the actual FC of the eastern coastal provinces and cities is higher than that observed in the southwest region (e.g. Yunnan, Tibet, and Qinghai). This is no surprise given differences in climatic conditions. For example, the average annual temperature variations in southwest regions are small. Moreover, the volume of vehicles is generally smaller resulting in less congestion (civilian vehicle density of Qinghai in 2015 for example was 1.1 person per square kilometer,[33] while in Beijing that number is 326.)[34] On the other hand, the altitude in the southwest is relatively high and the air thin, resulting in decreased wind resistance (at a given speed), which typically leads to lower a FC rate. Furthermore, at high altitudes, the engine intake pressure decreases (as air volume decreases), leading to a further decrease in FC.[35] Eastern and northern regions are characterized by more extreme temperature variations and higher urban population densities. In Shanghai, for example, the average actual FC rate among sampled data input was 11.4L/100km, the third highest in China.

Figure 32: Geely Boyue 2016 1.8TD AT model average FC Across different provinces



3.3.2 Temporal FC gap analyses results

Based on spatial and urban representation, six typical cities were chosen to enable an analysis of

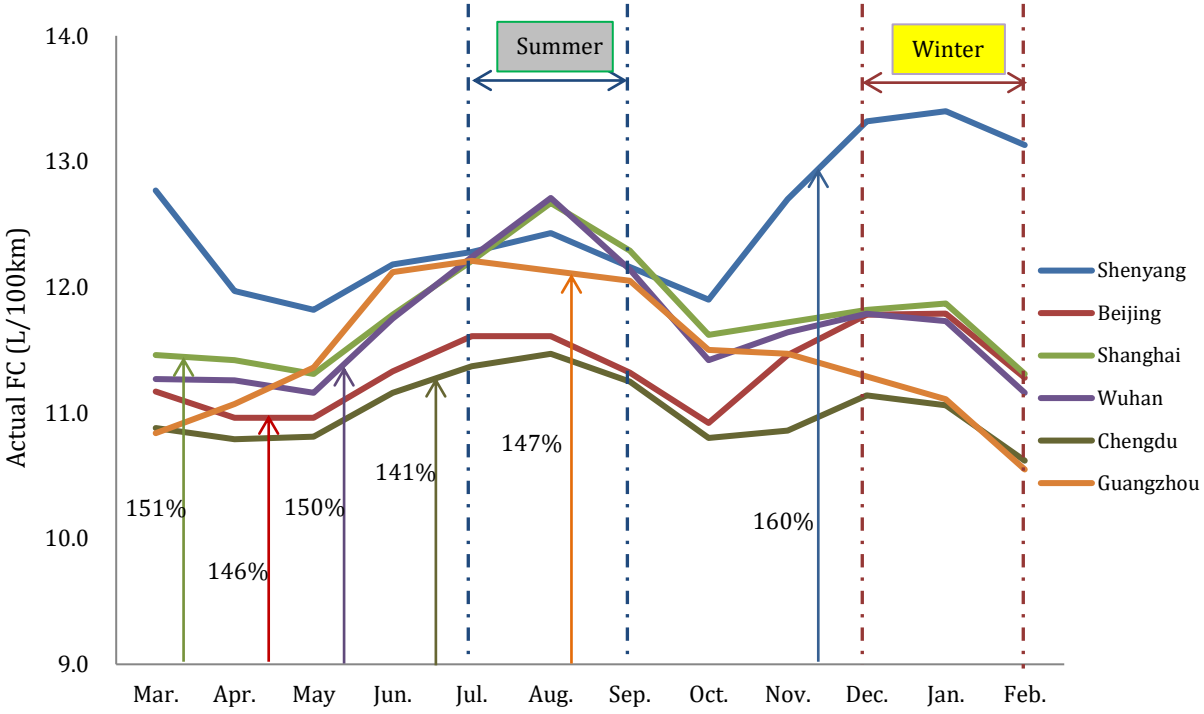
[33] 2015 Qinghai Statistical Bulletin. *Qinghai Statistical Information Network* www.qhtjj.gov.cn/tjData/yearBulletin/201602/t20160229_39207.html

[34] 2015 Statistical Yearbook of Beijing. *Beijing Statistical Bureau*. http://www.bjstats.gov.cn/nj/main/2016-tjnj/zk/indexch.htm

[35] Wang Yuwei, Liu Le, Zhao Wei, Lu Hongyu, Gong Jinhui, Study on light-duty vehicles' emissions and fuel consumption in high altitudes. *Auto Tech* 2014：48-52. http://mall.cnki.net/magazine/article/QCKJ201403010.htm

the temporal and spatial impacts on FC performance. From north to south, the selected cities are: Shenyang, Beijing, Shanghai, Wuhan, Chengdu, and Guangzhou. Demonstrated in **Figure 33**, the following are the main conclusions of the analysis: (1) Shenyang has the highest actual FC, while Chengdu has the lowest. These results are in line with the above explanation; (2) Wuhan and northern cities experience the highest FC rate during the winter months, while all six cities see FC reductions during the winter and a FC rate increase in the summer; (3) during the Spring and Fall, the six cities show a fairly consistent FC rate; (4) overall temporal variations reaffirm the belief that seasonal changes impact FC performance. Air conditioning usage and cold start are also major contributors to climatic impacts on FC performance.

Figure 33: Geely Boyue 2016 models 1.8TD AT average FC across different cities



Shenyang's annual average FC rate was 12.48L/100km, indicating a reported-versus-actual FC gap as high as 160%. The maximum FC of 13.57L/100km was reached in January, while the minimum FC of 11.64L/100km appeared in May.

Beijing's annual average FC rate was 11.34L/100km, indicating a FC gap of 145%. The maximum FC of 11.85L/100km was reached in January, while the minimum FC of 10.79L/100km appeared in October. The minimum FC may result from favorable climatic conditions (Fall), or from decreased congestion in urban areas during the national holiday.

Shanghai's annual average FC rate was 11.79L/100km, indicating a 151% FC gap, higher than that of Beijing by six percentage points. Unlike the two cities above, Shanghai's highest FC rate occurred at the beginning of August, reaching 12.73L/100km. Its minimum FC rate was 11.1L/100km in February. This is a clear result of the mild winter as oppose to extreme summer heat.

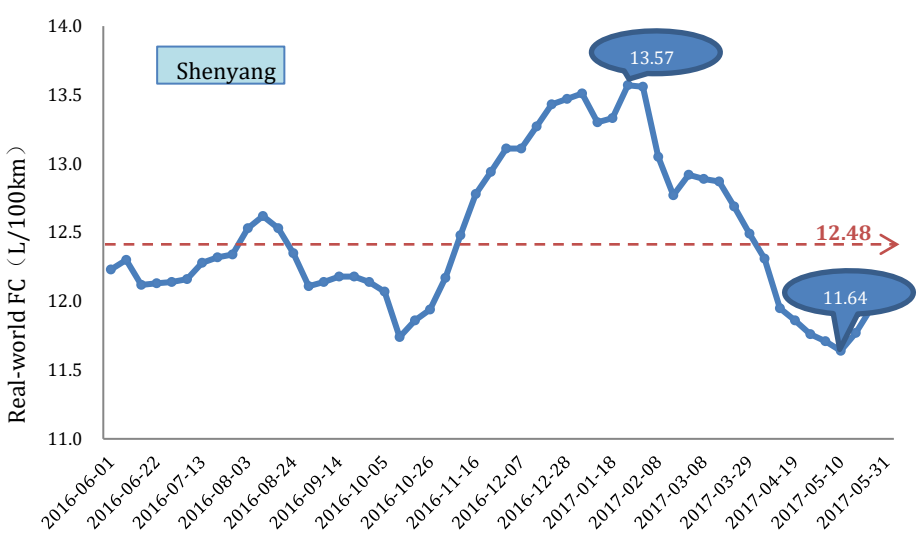
Wuhan's annual average FC rate was 11.69L/100km, marking a 150% FC gap. The maximum fuel consumption of 12.84L/100km appeared in early August, and the minimum fuel consumption of

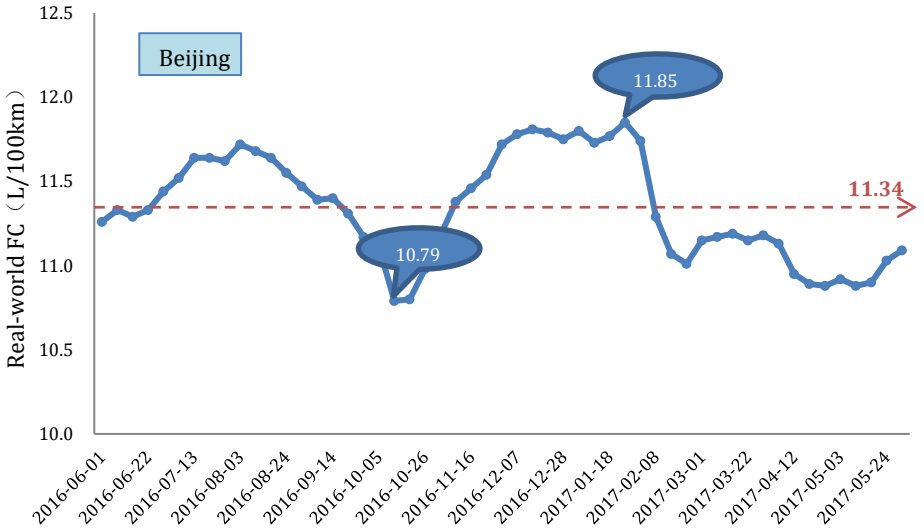
11L/100km appeared in mid-February. Wuhan's FC performance is very similar to that of Shanghai, not surprisingly given their geographic and climatic similarities.

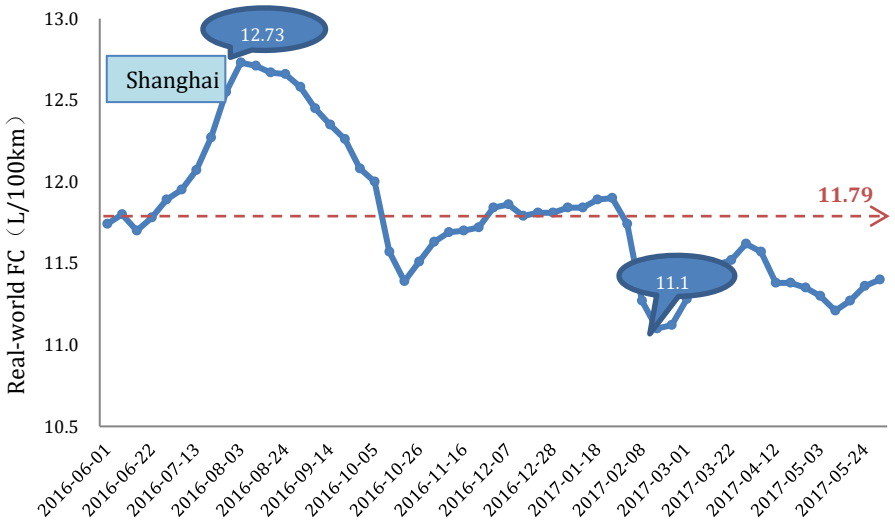
Chengdu's annual average FC rate of 11.04L/100km, indicates a FC gap of 141%, the lowest among the six cities examined here. Although the city's fuel consumption curve is similar to that of Shanghai and Wuhan, the FC gap trend is more moderate, presumably because of Chengdu's mild sub-tropical monsoon climatic conditions. The maximum FC rate of 11.52L/100km appeared at the end of August, and the minimum FC rate of 10.49L/100km appeared in early March.

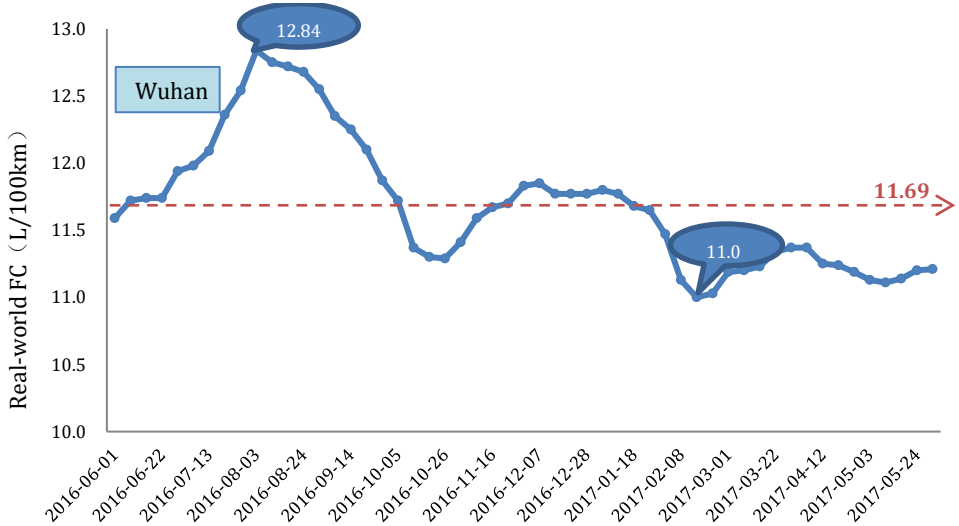
Guangzhou's annual average FC rate of 11.48L/100km, indicates a FC gap of 147%, higher than Chengdu and Beijing. From the end of May to early October, the FC rate reached a maximum of 12.26L/100km in June. A minimum FC rate of 10.32L/100km was reached in February.

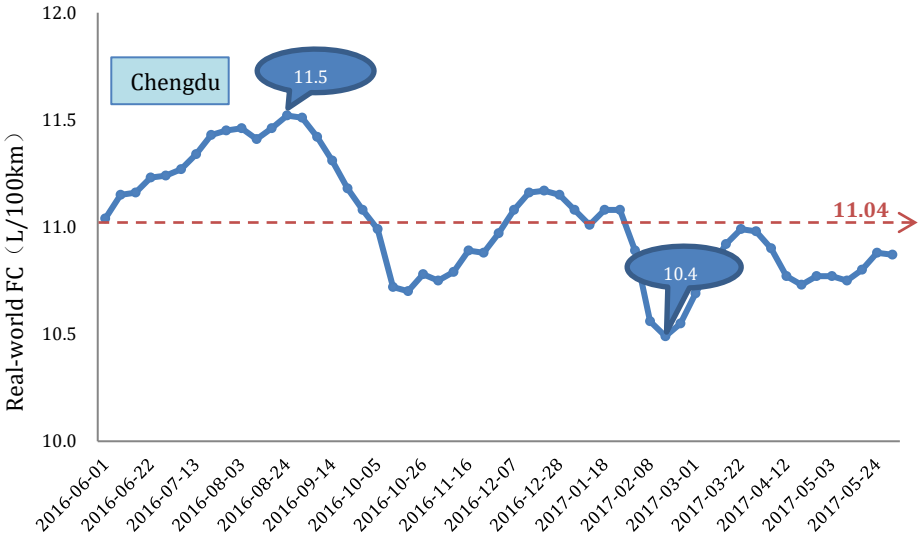
Figure 34: FC rate yearly changes of Geely Bo 2016 models 1.8TD AT in different cities

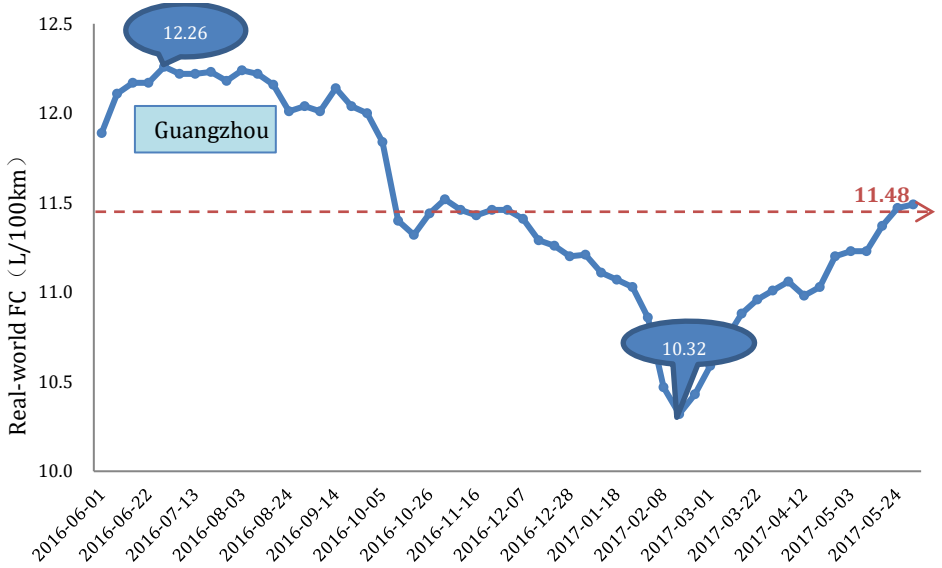









Chengdu
11.5
11.04
10.4
Real-world FC（L/100km）
12.0
11.5
11.0
10.5
10.0
2016-06-01
2016-06-22
2016-07-13
2016-08-03
2016-08-24
2016-09-14
2016-10-05
2016-10-26
2016-11-16
2016-12-07
2016-12-28
2017-01-18
2017-02-08
2017-03-01
2017-03-22
2017-04-12
2017-05-03
2017-05-24


Guangzhou
12.26
11.48
10.32
Real-world FC（L/100km）
12.5
12.0
11.5
11.0
10.5
10.0
2016-06-01
2016-06-22
2016-07-13
2016-08-03
2016-08-24
2016-09-14
2016-10-05
2016-10-26
2016-11-16
2016-12-07
2016-12-28
2017-01-18
2017-02-08
2017-03-01
2017-03-22
2017-04-12
2017-05-03
2017-05-24

3.4 By-model FC gap analysis

3.4.1 Selected brand FC comparison

BearOil FC sample coverage of more than 80 brands (over 100 samples per brand) show that the overall model of the actual FC difference of 124% (based on data from 2008 to 2016). As demonstrated in **Figure 35**, the majority of brands had a FC gap higher than the average. Listed in

Figure 36, brands with the highest FC gaps were SMART (141%), BMW (140%), Volvo (139%), Geely Automobile (139%), and BYD (136%). Brands with the lowest FC gaps were FAW (108%), Riich (108%), DongFeng Xiaokang (109%), Huatai (112%), and Everus (112%). **Figure 37** shows the difference in actual versus reported FC of 29 brands with 1000 samples per year between 2014 and 2016. The majority of the brands show a U-curve in FC performance.

It is worth noting that the sample is derived from different drivers at different location and under different driving conditions within China. This may incur high variations that impact the by-model averages between models.

Figure 35: Selected model's FC gap distribution

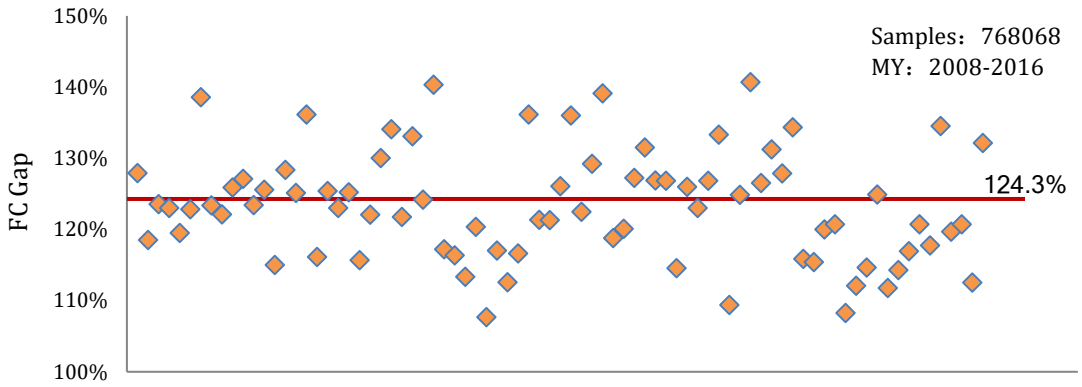
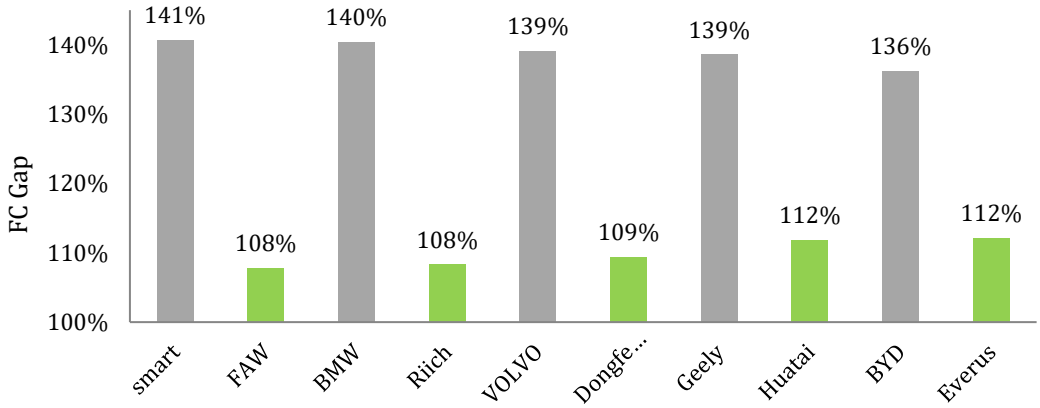
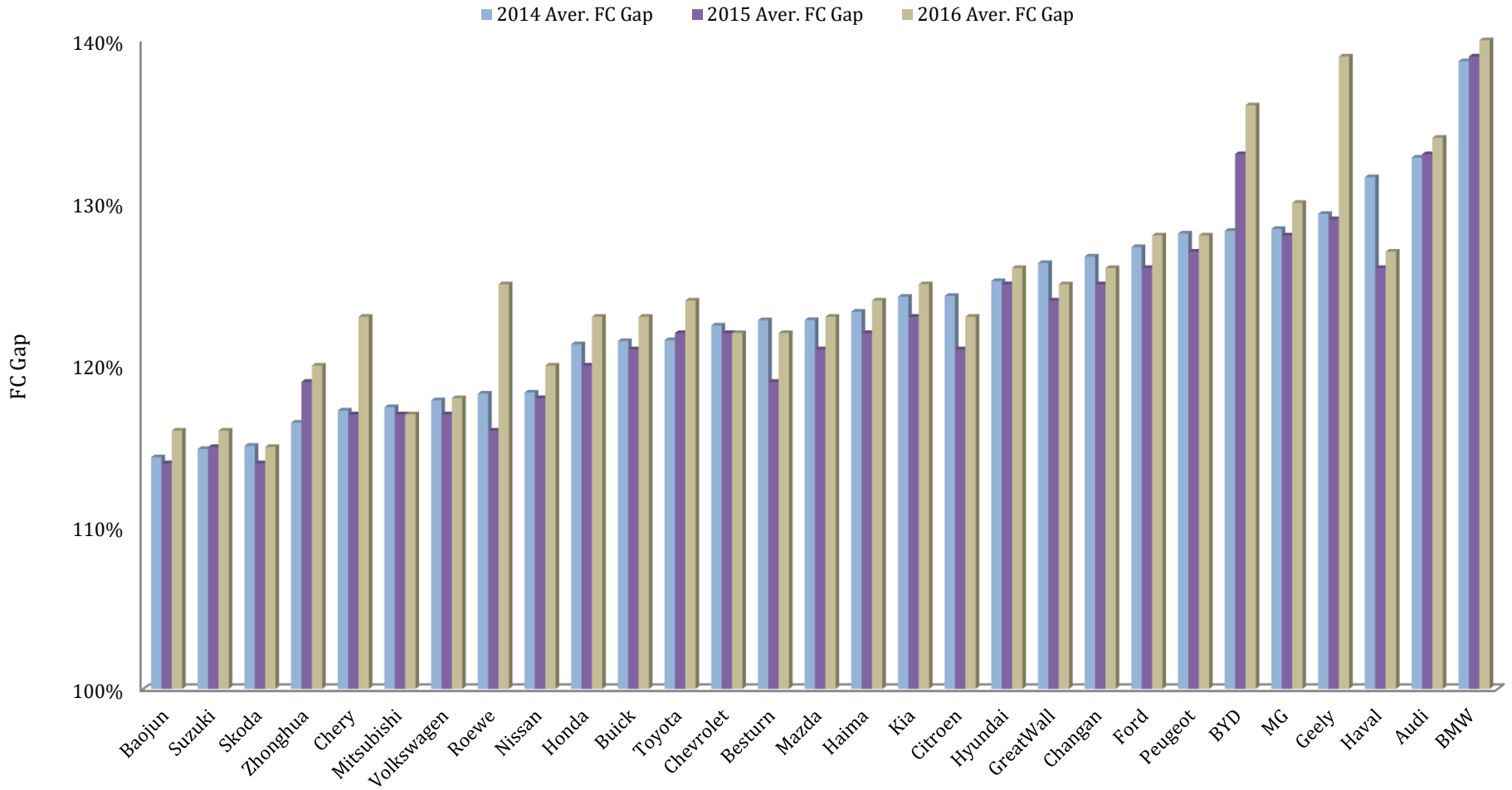


Figure 36: Comparative FC gap of top 5 least and best performing models



***Note**: Brand analysis is based on data from 2008 to 2016.*

Figure 37: Comparative FC gap of top 29 brands (2014-2016 data)



***Note**: Brand analysis is based on data from 2008 to 2016.*

3.4.2 Brand type FC gap comparison (importing, JV, independent)

With more than 120 vehicle companies, China's auto industry is complex. Companies are typically divided into two types based on the location of their manufacturing: importers and domestic. Another level of categorization further divides domestic manufacturers by their source of capital: joint ventures (JVs) and independent manufacturers. JVs are foreign brands that have partnered with local brands and are manufacturing locally. The three types of brands are usually different from each other by design, vehicle technology, model segmentation, and other aspects. According to the BearOil FC data sample collected from 2014 through 2016, shown in **Figure 39**, importers, JVs and independent passenger car models have an average actual-versus-reported FC gap of 125.5%, 125.3%, and 130.4% respectively. Although the distribution of model FC gap is rather high for each of the brand types, as demonstrated in **Figure 38**, it is evident that independent manufacturers tend to have higher FC gaps than brands that are fully or partially foreign (e.g. importers and JVs). That said, several independent brads achieved mild FC gap, including: FAW, Riich, Dongfeng, and Huatai. Both JVs and independent brands show an increased FC gap during 2014-2016, while imported brands reflect a dramatic decrease in the FC gap during 2015-2016. **Table 6** presents the market share by manufacturer types, demonstrating the market impact of independent brands where the FC gap is larger than that of JVs and importers.

Figure 38: FC gap by brand type (2014-2016 data)

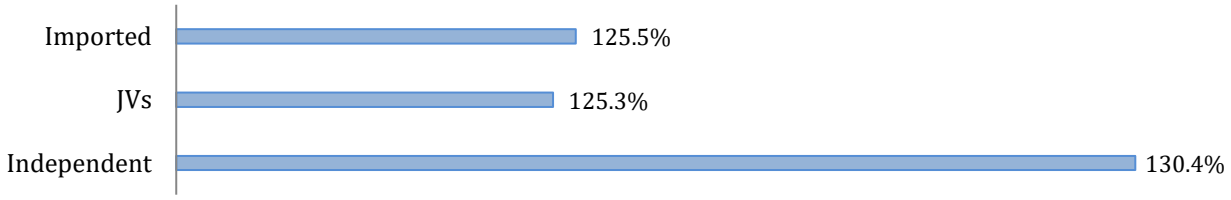


Figure 39: By-brand type FC gap development during 2014-2016

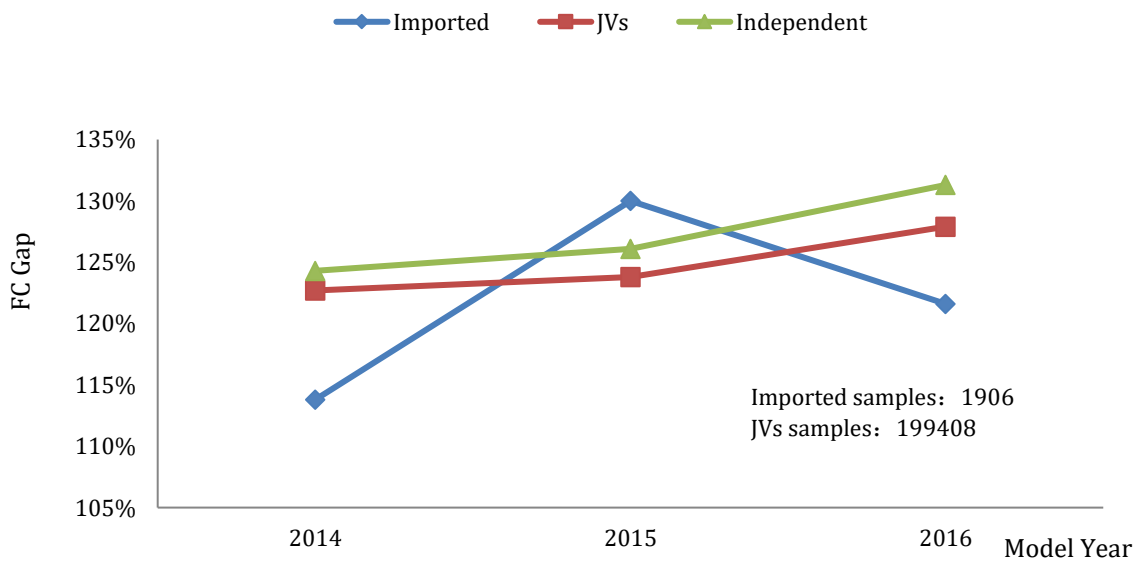


Table 6: Market share variation of imported, JV, and independent vehicles (based on the BearOil database)

	Imported	JVs	Independent
2014	1.2%	68.8%	30.0%
2015	0.4%	63.7%	35.8%
2016	0.1%	49.9%	50.0%

3.5 Best-selling passenger vehicles actual and certified FC gaps

According to the statistics of the passenger vehicle federation, in 2016 the annual sales of China's top 100 models was over 16.4 million, accounting for 69.5% of the total national passenger car sales.[36] This section attempts to shed light on the incremental FC gap of the rapidly growing national passenger vehicle market.

The smallest gap achieved by bestselling models was 110%, while the largest gap was 160%, indicating a variation of 50%. The average actual and reported FC gap was 129% (higher than last year's 126%) and lower than the total market average gap of 131%.

Figure 40: FC gap of the top 100 best-selling models in 2016

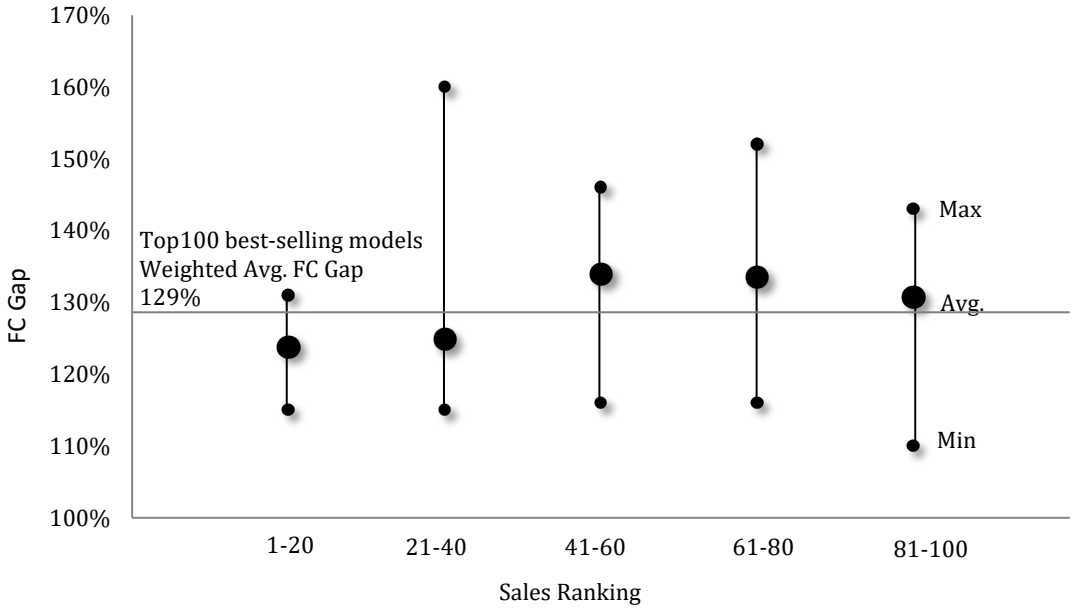


Figure 41 presents the FC gap performance of China's top 10 fastest and slowest growing models in 2016 (among this year's bestselling 100 models). The fastest growing models saw a gap of 127% on average, with the fastest growing achieving a gap well below the average (120%). Models with slower sales volumes achieved a better FC performance with an average FC gap of 123% (however there was much fluctuation).

[36] http://www.sohu.com/a/124082755_372777

Figure 41: FC gap of China's fastest growing models, and slowest growing models (within bestselling top 100)

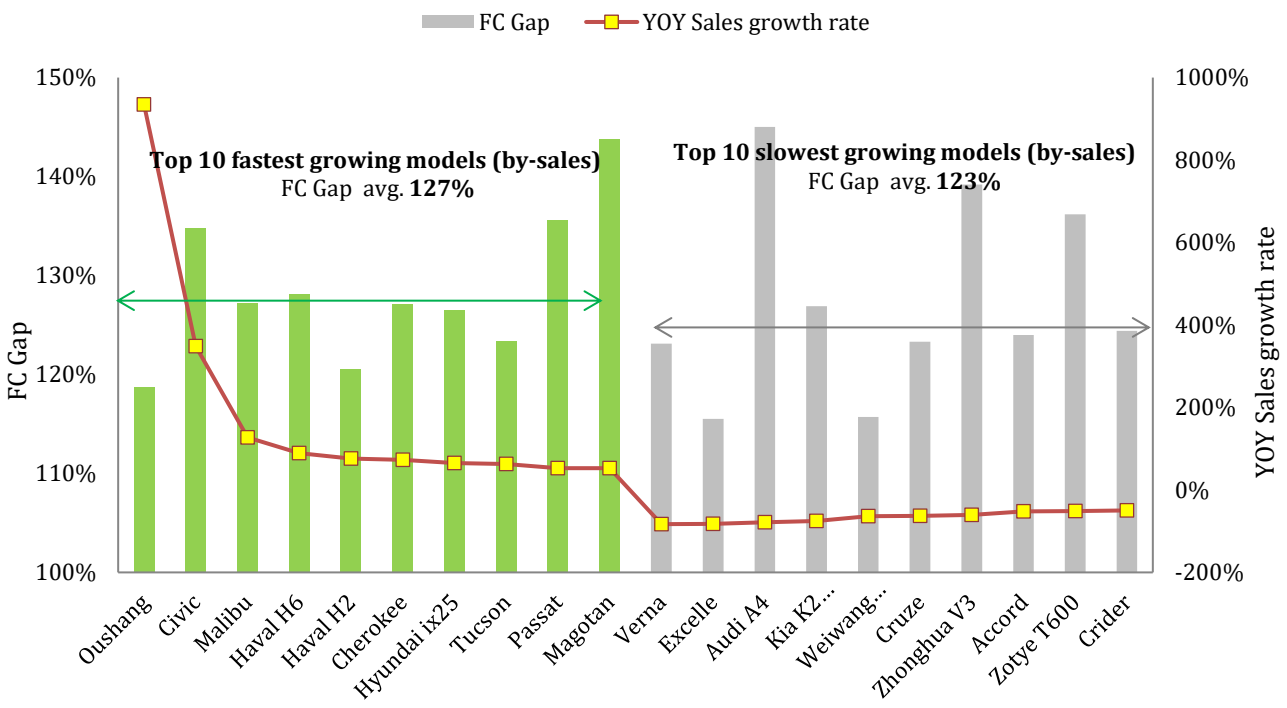
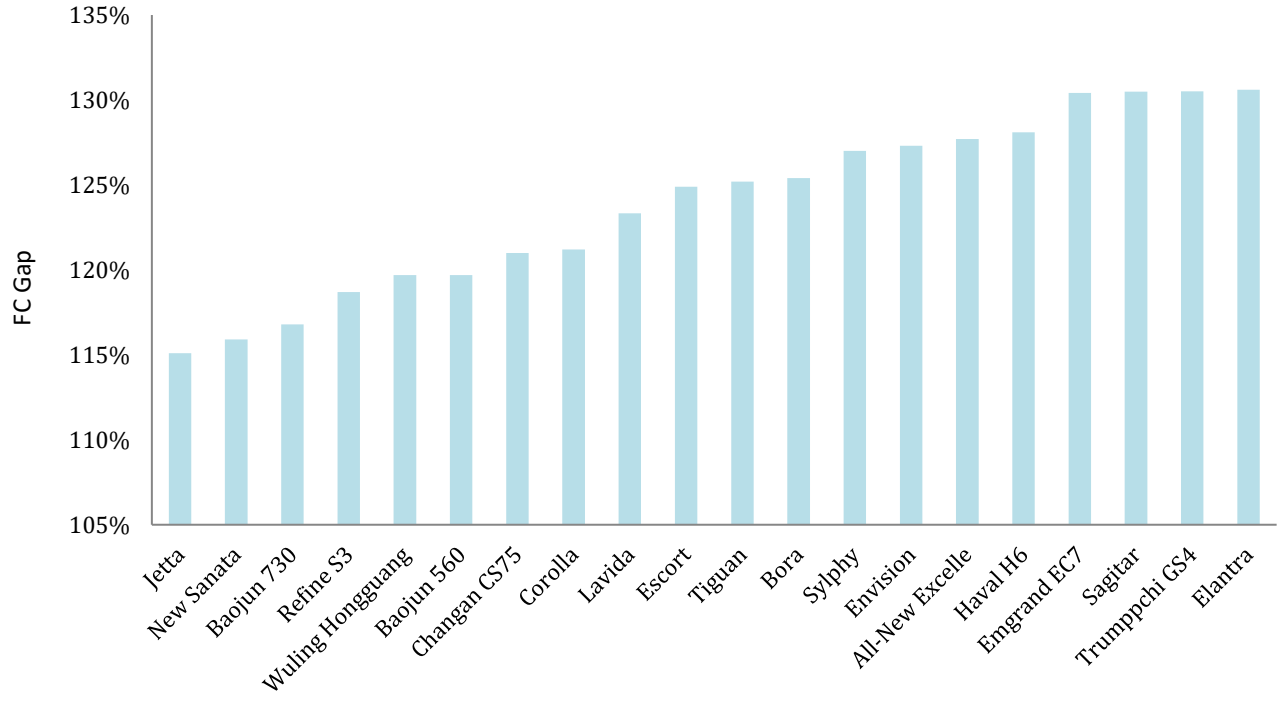


Figure 42 shows the top 20 selling models in order of their FC gap. The lowest FC gap was achieved by Volkswagen Jetta, which was ranked 7 in 2016 by sales volume (over 340,000), while the largest FC gap (31%) was reached by Trumpchi GS4 And Hyundai Elantra, coming in at 9 and 15 in by-sales ranked models for 2016, respectively.

Figure 42: FC gap comparison of top 20 best-selling models



4. Conclusions

This report affirms and expands the results of the previous two research reports. Taking the initial feasibility FC gap study of 2015[37] and the following one in 2016,[38] this study is based on a larger data set provided by the BearOil app, which has undergone a cleaning process detailed in section 2.2.4. Key findings of this 2017 report are as follows:

1. The FC gap has been increasing over time from an average of 112% in 2008 to 127%, 129%, and 131% in the last three years. This trend reaffirms that the observed FC gaps growth elsewhere is also evidenced in China (the International Council of Clean Transportation (the ICCT), states the growth in FC gaps in Europe increased from 9% to 42% between 2001 and 2016).[39]
2. AT vehicles typically have a larger actual-versus-reported FC gap than MT vehicles, averaging 132% and 126% respectively. As AT vehicles accounted for nearly 60% of cars in China in 2016 and their share increases annually (from 32.8% and nearly 54% in 2008 and 2015 respectively), the average FC gap of passenger vehicles is likely to grow faster over time.
3. As in last year, multi-purpose vehicles (MPVs) achieved one of the lowest average FC gaps among all vehicle segments, a mere 121% FC gap with an increase of 7% between 2010 and 2016 (1% on average per year, secondary only to the large vehicle segment of which data input are significantly fewer). Compact cars and SUVs, on the other hand, saw an increase in FC gap of 6 and 4 percentage points or increase to 132% and 130% gap, respectively. Their gap grew by 16% and 12% over the past five years, respectively. SUVs, in particular, have seen significant market growth in recent years.
4. In this report, recognizing the role vehicle weight increase plays in China's auto development landscape, a by-weight analysis of FC gap was added. We found that the FC gap of vehicles weighing less than 1200kg or between 2110kg and 2280kg is the smallest, while models with curb weight ranging 1660kg and 1770kg typically have the largest FC gap (for example: Mercedes-Benz E-class, BMW 5 Series, Audi A6, Harvard H5, and many of China's SUV models).
5. While the gap between the actual FC of vehicles and the FC reported by the manufacturers is very clear, it is arguably overlooked by policy-makers; our analysis demonstrates that the gap between the actual FC of vehicles and their standard limit (blue line in the below figure) is too - far from negligible (in particular, vehicles weighting over 1600kg tend to have higher FC deficiency, suppressing 120%) - this gap in standard implementation should alert policy-makers, and calls for proper evaluation and enforcement of the standard.
6. By examining over 150,000 user data samples of six models, it is evident that turbocharged technology is effective with MT much more than it is with AT, and that model performance varies much between TC and NA for the same series (for example, Ford had a FC gap exceeding 10.8%).
7. Performing as sample model for FC, temporal and spatial variations (31 locations, throughout all months of the year), Geely Boyue 2016 1.8TD AT model FC gaps demonstrated how northern

[37] Ding Ye, Maya Ben Dror et al., Real-world and Certified Fuel Consumption Gap Analysis. *iCET*. http://www.icet.org.cn/admin/upload/2015080439650285.pdf
[38] Qin Lanzhi, Maya Ben Dror et al., 2016 Real-world Passenger Vehicle Fuel Consumption Analysis. *iCET*. http://www.icet.org.cn/english/admin/upload/2016092336546493.pdf
[39] From Laboratory to Road-A 2017 update. *ICCT*. http://www.theicct.org/sites/default/files/publications/Lab-to-road-2017_ICCT-white%20paper_06112017_vF.pdf

regions tend to have higher FC rates (led by Shenyang), and how winter increases FC rates in northern regions while summer increases FC rates in southeastern regions (demonstrated by Shanghai and Wuhan).

8. The average FC gap for China's 2016 top selling models was 129%, lower than the national average (but 2.4% higher than last year's average). The smallest gap achieved by bestselling models was 110%, while the largest gap was 160%, indicating a variation of 50%.

There are multiple factors that impact the increase in gap between actual and certified (laboratory-reported) FC, which ought to be further investigated in order to reverse this trend and strengthen the effectiveness of China's fuel consumption standard. For example:

I. The standard design could be adjusted to accommodate for issues of FC gap, for instance, by:

- Adjusting for anthropogenic and location-specific driving conditions (geographical conditions, urban transport planning etc.), which have an effect on actual FC, could improve the representativeness of China's FC test-cycle; luckily a new China cycle, meant to replace the NEDC, is underway.

- Location-based FC conversions could be developed to support the formation of local FC standards that align with national and local FC goals.

- Additional vehicle quality standard could be implemented for reversing the effects vehicle segmentation and weight growth have on FC (e.g. vehicle light materials, technological specification etc.).

II. Studies could investigate the factors impacting FC gap under real-world driving conditions, such as, altitude, temperature, humidity, driving conditions'. Research based on new data sources, with large data volumes of a variety of vehicles in different locations is key for generating actionable information.

III. Last but not least, this report further highlights the need for independent and accountable third-party verification of the implementation of automobile FC standards.[40]

[40] Refer to iCET Sep 21 workshop news for further information regarding FC gap recommendations: http://www.icet.org.cn/english/newsroom.asp?fid=16&mid=17.

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Appendix

Appendix 1 By-brand FC gaps

Brand	Fuel Consumption Gap	Sample size
FAW	108%	3225
Riich	108%	310
Dongfeng Xiaokang	109%	689
Huatai	112%	249
Everus	112%	294
Zhongxing	113%	133
Venucia	113%	2934
Wuling	113%	4024
Lifan	114%	244
BAIC	115%	974
Hafei	115%	289
Skoda	115%	22345
Liebao	115%	458
Baojun	116%	8075
Karry	116%	459
Suzuki	116%	17490
Fiat	116%	4046
Southeast Motor	117%	2834
Dongfeng fengdu	117%	210
Dongfeng fengshen	117%	3109
Mitsubishi	117%	5097
Lotos	118%	200
Volkswagen	119%	64943
Zotye	119%	1776
Nissan	120%	38664

Chrysler	120%	174
Weiwang	120%	440
Changan Commercial	120%	1718
Zhonghua	120%	3357
Changhe	121%	156
Dongfeng	121%	205
Geely	121%	35491
Dongfeng fengxing	121%	2550
Subaru	121%	2557
Besturn	122%	5890
JAC	122%	6763
Chevrolet	122%	34792
Lexus	123%	2113
Honda	123%	36701
Buick	123%	39289
Landwind	123%	902
Citroen	123%	12368
Chery	123%	34810
Mazda	123%	24963
Toyota	124%	55451
Haima	124%	5696
Renault	125%	685
SAIC Maxus	125%	266
Kia	125%	19079
Roewe	125%	10036
Greatwall	125%	15286
Changan	126%	23268
Hyundai	126%	30545
Dongfeng fengguang	126%	934

JEEP	126%	2541
Ciimo	127%	656
Dodge	127%	808
Qoros	127%	991
Haval	127%	27237
BAIC Senova	127%	1514
Yusheng	128%	550
Ford	128%	66728
Peugeot	128%	21551
Cadillac	129%	2108
MG	130%	6497
DS	131%	594
BAC Huansu	132%	1266
Lincoln	132%	130
GAC Trumpchi	133%	5781
LandRover	133%	734
Audi	134%	6230
MINI	134%	483
Cowin Auto	135%	188
Luxgen	136%	2476
Benz	136%	2744
BYD	136%	17641
Volvo	139%	2103
BMW	140%	5317
Smart	141%	666
Weighted Average	**124.3%**	
Total samples	**768068**	

Appendix 2 National real-world FC of Geely Boyue 1.8 T model

Province*	Real-world FC	Of average FC	Of combined test-cycle FC
Xizang	10.38	93.1%	133.1%
Qinghai	10.47	93.9%	134.2%
Yunnan	10.48	94.0%	134.4%
Ningxia	10.70	96.0%	137.2%
Sichuan	10.75	96.4%	137.8%
Shanxi	10.76	96.5%	137.9%
Gansu	10.78	96.7%	138.2%
Shaanxi	10.82	97.0%	138.7%
Fujian	10.94	98.1%	140.3%
Jiangsu	10.96	98.3%	140.5%
Guangxi	10.98	98.5%	140.8%
Beijing	11.02	98.8%	141.3%
Tianjin	11.06	99.2%	141.8%
Guizhou	11.07	99.3%	141.9%
Hainan	11.11	99.6%	142.2%
Shandong	11.15	100.0%	142.9%
Jiangxi	11.16	100.1%	143.1%
Chongqing	11.17	100.2%	143.2%
Anhui	11.19	100.4%	143.5%
Hubei	11.19	100.4%	143.5%
Guangdong	11.23	100.7%	144.0%
Hebei	11.23	100.7%	144.0%
Xinjiang	11.29	101.2%	144.7%
Hunan	11.31	101.4%	145.0%
Henan	11.35	101.8%	145.5%
Zhejiang	11.36	101.9%	145.6%
Shanghai	11.40	102.2%	146.2%

Nei Mongol	11.49	103.0%	147.3%
Liaoning	11.93	107.0%	152.9%
Jilin	12.33	110.6%	158.1%
Heilongjiang	12.61	113.1%	161.7%
Arithmetic Average	**11.15**		**143.0%**

Appendix 3 FC gaps of 2016 top 100 best-selling models

Sales Ranking	Model Name	Segment	FC Gap*	Sample Size
1	Wuling Hongguang	MPV	120%	39
2	Haval H6	SUV	128%	2347
3	Lavida	Compact	123%	61
4	All-new Excelle	Compact	128%	3743
5	Baojun 730	MPV	117%	1197
6	Sylphy	Compact	127%	2288
7	Jetta	Compact	115%	2085
8	Sagitar	Compact	130%	23
9	Trumpchi GS4	SUV	131%	1071
10	Baojun 560	SUV	120%	972
11	Corolla	Compact	121%	2027
12	Escort	Compact	125%	4621
13	New Sanata	Compact	116%	781
14	Envision	SUV	127%	1185
15	Elantra	Compact	131%	267
16	Tiguan	SUV	125%	555
17	Emgrand EC7	Compact	130%	23
18	Bora	Compact	125%	735
19	Changan CS75	SUV	121%	1192
20	Refine S3	SUV	119%	1307

21	Haval H2	SUV	121%	2442
22	Kia K3	Compact	135%	781
23	Cruze	Compact	123%	235
24	Passat	Mid-size	136%	340
25	Honda CR-V	SUV	122%	442
26	X-Trail	SUV	123%	300
27	All-new Tucson	SUV	123%	877
28	VW Golf	Compact	129%	1552
29	Changan CS35	SUV	127%	735
30	All-new POLO	Small	118%	1820
31	Magotan	Mid-size	144%	138
32	Vezel	SUV	126%	138
33	Honda XR-V	SUV	121%	1247
34	Levin	Compact	129%	2090
35	EADO	Compact	129%	498
36	Verano	Compact	134%	113
37	Octavia	Compact	115%	674
38	Honor	MPV	127%	147
39	Mistra	Mid-size	130%	592
40	BMW 5	Large	160%	38
41	Lamando	Compact	——	——
42	Qashqai	SUV	127%	1215
43	Sail Saloon	Small	118%	139
44	Geely Vision	Compact	146%	1766
45	Accord	Mid-size	124%	616
46	Audi A6	Large	146%	66
47	Mazda 3	Compact	125%	3124
48	Elantra	Compact	135%	433
49	BYD F3	Compact	124%	546

50	Audi Q5	SUV	127%	374
51	Arrizo 5	Compact	146	4847
52	Edge	SUV	128%	631
53	Weiwang M30	MPV	116%	57
54	Focus Saloon	Compact	133%	514
55	Tiggo 3	SUV	122%	949
56	Auchan	MPV	119%	455
57	Vios	Small	128%	373
58	Verna	Small	123%	219
59	RAV4	SUV	133%	363
60	Kuga	SUV	135%	28
61	Fit	Small	128%	999
62	Hyundai ix25	SUV	127%	649
63	Zotye T600	SUV	130%	58
64	Kia K2 Saloon	Small	127%	975
65	Boyue	SUV	142%	5496
66	Huansu H3	MPV	136%	33
67	Benz Class-C	Mid-size	152%	199
68	Excelle	Compact	116%	1768
69	Cherokee	SUV	127%	766
70	Zhonghua V3	SUV	139%	300
71	New Mondeo	Mid-size	146%	143
72	Haima S5	SUV	126%	297
73	Camry	Mid-size	137%	818
74	Peugeot 408	Compact	115%	200
75	BYD Song	SUV	——	——
76	Huansu S3	SUV	130%	186
77	Fengguang 330	MPV	126%	23
78	Audi A4	Mid-size	145%	150

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79	BMW 3	Mid-size	136%	462
80	Focus Hatchback	Compact	138%	545
81	Highlander	SUV	128%	1178
82	Lingzhi	MPV	113%	58
83	TEANA	Mid-size	127%	188
84	Domy X5	SUV	110%	29
85	Roewe RX5	SUV	136%	2454
86	Honda Civic	Compact	135%	1677
87	Audi Q3	SUV	139%	89
88	Crider	Compact	124%	421
89	Benz GLC	SUV	143%	78
90	Elysee	Compact	125%	578
91	Fengguang 580	SUV	129%	441
92	Malibu	Mid-size	127%	554
93	Audi A3	Compact	141%	238
94	Southeast DX7	SUV	116%	59
95	Roewe 360	Compact	133%	44
96	Liebao CS10	SUV	117%	44
97	Senova X25	SUV	124%	182
98	LaCross	Mid-size	132%	194
99	Changan CX70	SUV	115%	410
100	Land Wind X	SUV	124%	202
Average/Total			129%	81919