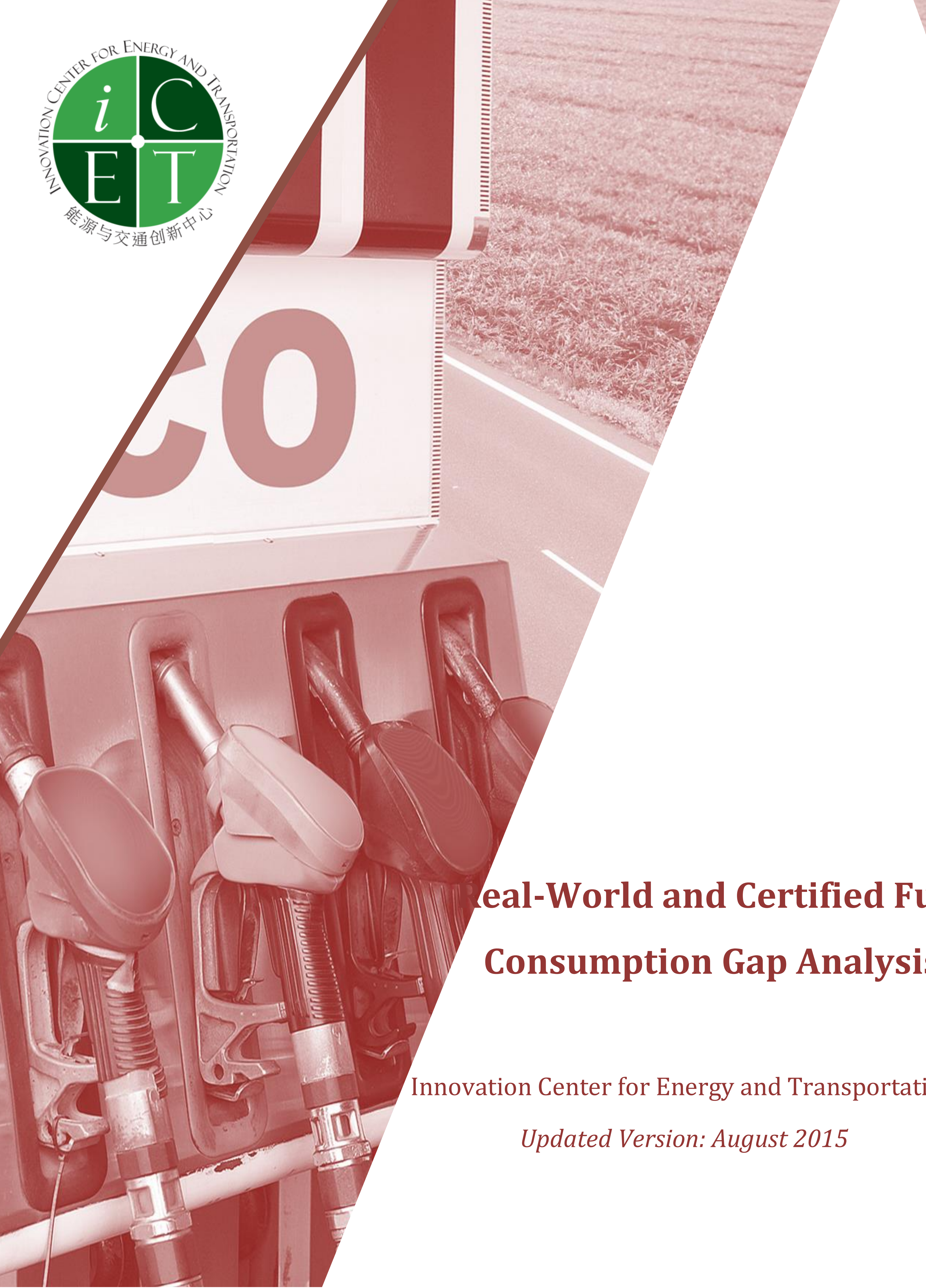

Real-World and Certified Fuel Consumption Gap Analysis

Innovation Center for Energy and Transportation

Updated Version: August 2015

REAL-WROLD AND CERTIFIED FUEL CONSUMPTION GAP ANALYSIS

UPDAED VERSION: August 10, 2015

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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 and 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 tones
Real-world FC	FC values calculated based on ***BearOil App*** users' data inputs.
Certified FC	Prior to vehicle sale in China (of either domestic production or imported cars), the vehicle should be 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 or/and government.
Effective figure	While each models has a real-world average FC resulted from BearOil App users' data ($M = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n}$), an average variance is used for deciding whether or not the average figure is effective ($s^2 = \frac{(x_1 - M)^2 + (x_2 - M)^2 + (x_3 - M)^2 + \cdots + (x_n - M)^2}{n}$).we only use data that in range $M-2s^2 < data < M+2s^2$
Private vehicle	Vehicle registered for private use.
Commercial vehicle	Freight vehicles and vehicles with over 9 seats (including driver's seat).
Passenger vehicles	All vehicle with up to 9 seats (including drivers' seat).

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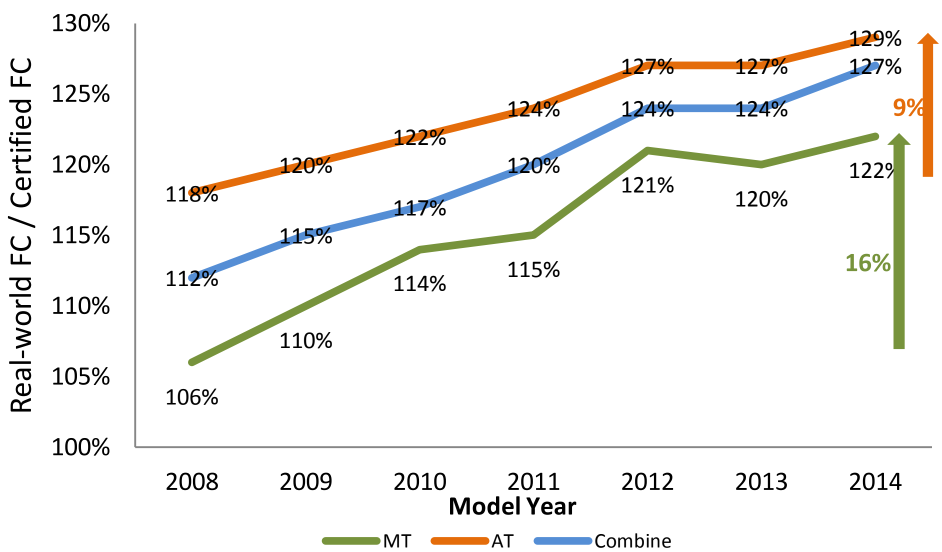
Executive Summary

Although the “light vehicle fuel consumption test method" standard was released over ten years ago (in 2004) and light vehicle labeling regulation was release over five years ago (in 2010), most vehicles’ actual fuel consumption is higher than the certified fuel consumption value. The status today is even more complex, since there is little information on actual fuel consumption levels. The Innovation Center for Energy and Transportation (*i*CET) in collaboration with the BearOil App collected over 210,000 valid samples of fuel consumption levels reported by drivers from various locations in China between 2008 and 2014. An average of the reported values was compared with China’s fuel consumption certification. The below figure illustrates the variations in FC gap along the years and between automated and manual vehicles.

Figure 1: China's 2008-2014 actual vs. real-world FC



Fuel consumption depends on driving conditions, related to both (i) anthropogenic driving (e.g. acceleration, air conditioning usage, load, tires pressure etc.) and (ii) external driving conditions (road elevation, outside temperatures, traffic congestion etc.). Both of these groups of factors may highly influence the actual FC level of a car, creating FC variations between different locations for various vehicle models and segments. This study exemplifies such variations.

Geographical and city design also impact variations between cities’ driving and resulted fuel consumption. In general, small car fuel consumption variations are relatively high between cities, and northern versus southern cities’ average FC also show high levels of variations. Furthermore, some of the driving conditions and vehicle features may not be well represented in the fuel consumption test cycle[1], therefore increasing the gap between real-world and testing score FC more than the uncontrolled minimum. For example, two

[1] China’s test drive cycle is based on the EU test cycle (NEDC), meaning a typical driving style of European city is the basis of China’s fuel consumption estimations for the case of China.

varying elements of the testing environment – vehicle mileage and outdoor temperature - may increase the FC certification score as they also increase. This study highlights these solvable sources of FC gaps.

Table 1: Factors influencing certified and real-world FC gaps

Anthropogenic factors	**FC impact**
Second gear start	Lower
Tires pressure fits recommended levels	Lower
Air-conditioning usage	Higher
Idle-Stop	Lower
Ethanol gasoline	Higher
Charging Battery	Higher
External factors	**FC impact**
Outside temperatures lower than type approval requirement	Higher
Barometric pressure decreases	Lower
Traffic congestion	Higher
Varying type approval test elements	**FC impact**
Vehicle reaches mileage from 3000km to 15000km	Lower
Outside temperatures increases from 20° to 30°	Lower

Background

China commenced its vehicle fuel consumption standards and policy research in 2001. In 2004, the State Committee for Standardization and the State Administration of Quality Supervision Inspection and Quarantine (AQSIC) jointly issued China's "light vehicle fuel consumption test method" (GBT19233-2003), in which the reference test cycle was the EC European Union test cycle (2004/EC/3) and came into force in November 2004. During the same year, the implementation of China's first mandatory "passenger car fuel consumption limits" (GB 19578-2004) began. Fuel consumption certification requirement, a useful FC standard management method, was finally announced in 2010.

Three phases of passenger car fuel consumption standards implementation have occurred since 2004. During the third phase, average fuel consumption of passenger car declined from 7.77L/100km in 2009 to 7.22L/100km in 2014. The fourth phase of the standard, "Fuel consumption limits for passenger cars" (GB 19578-2014) and "Fuel consumption evaluation methods and targets for passenger cars" (GB 27999-2014), was released on December 22, 2014 and projected to come into force as of January 1, 2016. A manufacturer-based average annual fuel consumption limit and target has also been set on top of the per-vehicle weight bin limits and targets, targeting a national FC average of 5L/100km by 2020.

*i*CET's 2013 *"Survey Report on Light-Duty Vehicle Fuel Consumption Labeling"* [2], conducted in 16 cities across China and included 114 4S dealers surveys and during 2012, found that 93% of car purchasers are concerned about fuel consumption levels; however, the majority lack confidence in the accuracy of the official reporting system. Consumers stated that through conversations with car dealers and friends as well as consulting online opinion posts, they expect to get a better grasp of actual fuel consumption levels.

BearOil App is China first independent mobile application aimed at collecting actual voluntary fuel consumption data across China and among various vehicle model drivers and publicizes its results to inform decision-making at the consumer, manufacturer, and policy-making levels. To date, over 400,000 drivers have downloaded the App since 2010 in 375 cities and representing 13,457 vehicle models.

This report attempts to flash out actual and certified FC gaps in China based on official FC certified data available and voluntary actual FC data collected from drivers across China through BearOil App and to suggest and assess reasons for causing the gap (e.g. by-model and by-location).

[2] http://www.icet.org.cn/admin/upload/2015061847871009.pdf

1. Methodology

The study is aimed at analyzing gaps between actual and certified FC levels across vehicles and locations in China, and assessing potential reasons for these gaps. Vehicle FC was limited to cars of categories M1, M2 and N1 not exceeding 3,500kg, which are manufactured between 2008 and 2014. The study therefore uses two sources of data: (i) certified FC collected from the Ministry of Industry and Information Technology website (MIIT)[3], which should also be displayed on a car front window at purchase; and (ii) BearOil App data sources by 210,000 drivers across 375 cities in China covering 13,457 car models.

1.1 Certified FC data

In 2010, China began implementing the light vehicle fuel consumption labeling regulation requiring every M1, M2 and N1 category vehicle sold in China fueled by either gasoline or diesel and has a curb-weight not exceeding 3500kg to be labeled with its type approval fuel consumption test results[4]. Domestic automobile production enterprises or imported car dealers are required to follow the "light vehicle fuel consumption test method" (GB/T19233) performed by certified testing sites across China[5] to confirm vehicles' projected fuel consumption data[6].

Fuel consumption test results conducted by the vehicle manufacturer or its representative are submitted to the testing agency responsible for the type test. Through a simulated urban and suburban driving conditions representative of typical driving conditions, carbon dioxide (CO2), nitric oxide (CO) hydrocarbon (HC) emissions as well as fuel consumption are calculated through a carbon balance method[7] by the authorized test site. The figure and table below demonstrate China's typical driving (test cycle speed per second divide), which is based on the EU test cycle (NEDC). Should an M category vehicle demonstrate FC levels which are higher or lower by maximum 4% from manufacturer's test results, the vehicle FC result through company/representative test is approved for labeling. All M1 vehicles with similar vehicle curb-weight and vehicle components produced by the same manufacturer are authorized to use the same FC level.

[3] http://chinaafc.miit.gov.cn/
[4]《轻型汽车燃料消耗量标示管理规定》 http://chinaafc.miit.gov.cn/n2257/n2339/c63900/content.html
[5] There are about 7 test sites in China certified by MIIT to perform type test approval: http://www.cvtsc.org.cn/cvtsc/zhxx/409.htm.
[6]《轻型汽车燃料消耗量标示管理规定》解读 http://chinaafc.miit.gov.cn/n2257/n2339/c63901/content.html
[7] GB/T 19233-2008 轻型汽车燃料消耗量试验办法 http://www.miit.gov.cn/n11293472/n11293832/n11294282/n14295506.files/n14295505.pdf

Figure 2: China's type test driving conditions

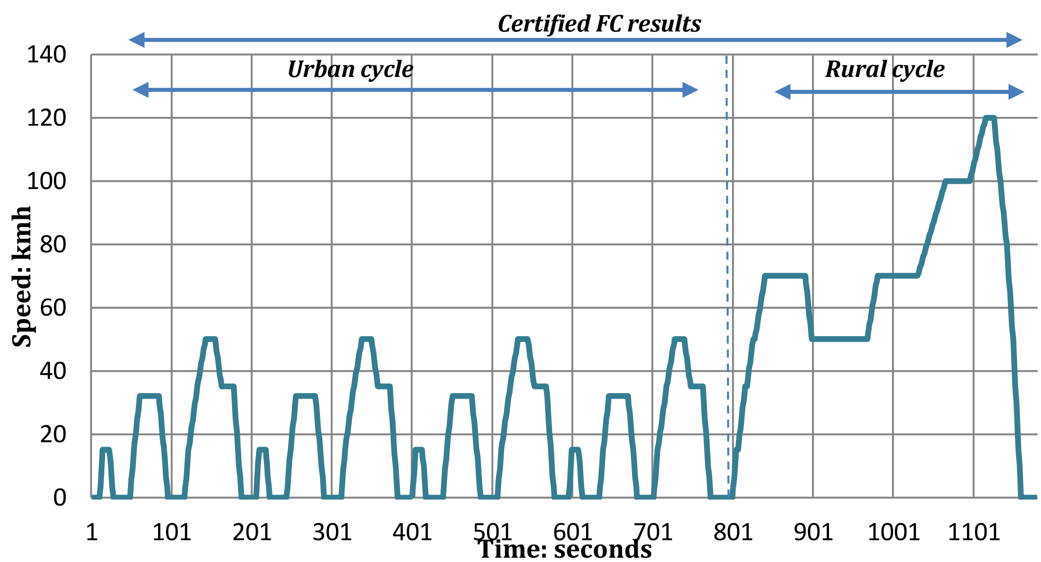


Table 2: China's FC type test divide

Test information	Suburban	Urban	Combine	% 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 and external elements (road elevation, outside temperatures, congestions etc.), real-world vehicle fuel consumption will vary between vehicles of the same model and may no longer be well represented by the labeled FC level. The below figures illustrates China's fuel consumption FC test cycle results as reported on the Ministry of Industry and Information Technology website and on the official labels meant to be place on the front window of vehicles for sale.

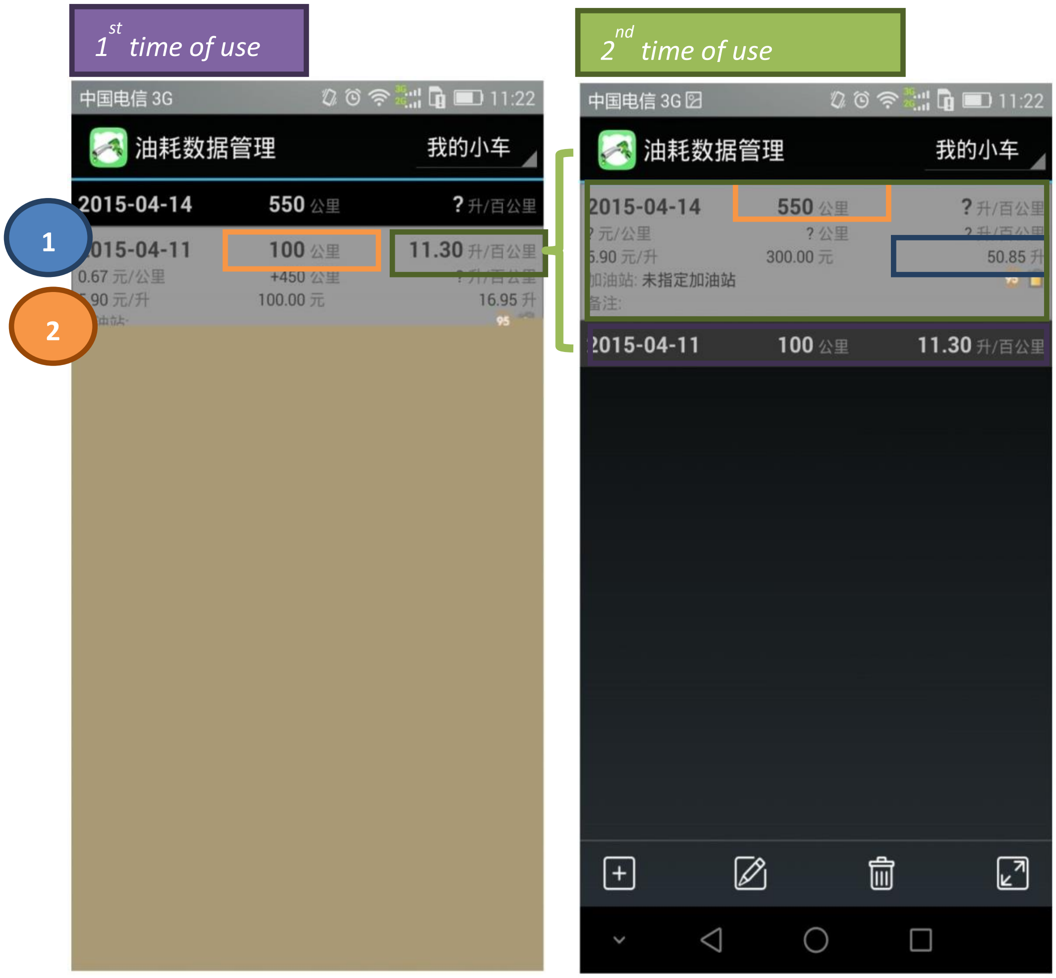
Figure 3: FC reporting on MIIT website and FC label

1.2 Actual fuel consumption

BearOil App is an independent organization devoted to the collection of voluntary FC data across China since 2010. BearOil App currently has over 400,000 users covering over 13,457 vehicle types in mainland China. The FC data is collected through the recording of fuelling volumes and mileage by the App owners (vehicle drivers). The user receives an immediate FC calculation for his or her own benefit, while the App stores this information in a large pool of data, which is meant to be available for the general public through periodic reports and an analyses option part of the App itself (available for the App user). It is hoped that the real-world FC data collected by this method will inform more sustainable decision-making at the corporate, consumer, and policy levels.

For the initial use, after the empty tank warning light turns on, App users will fill their vehicle tank until it is full. The user records (i) the fuel filling volume (e.g. 50.85L) in a dedicated slot and (ii) distance driven (e.g. 550km). From the second time onwards, the App uses stored user data to calculate the user's fuel consumption. The fuel volume is recorded by the user each time, while the distance is calculated by the App from the deduction of the last mileage from the current mileage, as demonstrated in the figures below. For example: 50.85L/(550km-100km)*100=11.3L per 100km driven.

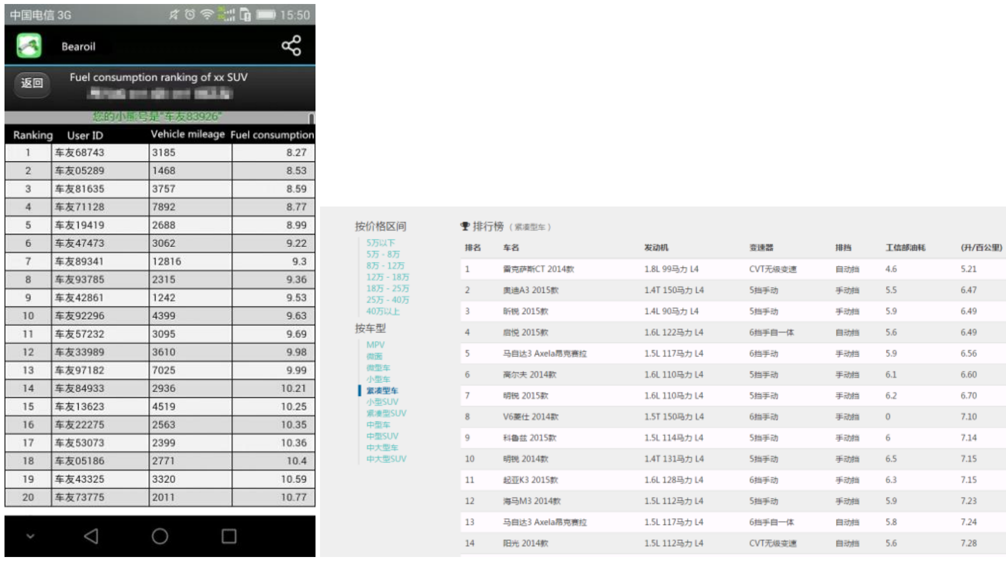
Figure 4: Snapshot of BearOil App



1. The fuel filling volume (say, 50.85L)
2. The distance traveled to date (say, 450(550-100)km)
3. The fuel consumption=50.85/450/100=11.3L/100km

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.

Figure 5: Snapshot of BearOil App real-world FC comparison - by model and BearOil website real-world FC ranking by segment.



Note: (i) on the left, by model comparison on BearOil App (ii) on the right, by segment comparison on BearOil website.

While each model has a real-world average FC calculated based on user-data inputs of BearOil App: $M = \frac{x_1 + x_2 + x_3 + \cdots + x_n}{n}$, an average variance is used for deciding whether or not the average figure is effective: $s^2 = \frac{(x_1 - M)^2 + (x_2 - M)^2 + (x_3 - M)^2 + \cdots + (x_n - M)^2}{n}$. This study only uses data that is between the following range: $M\text{-}2s^2 < \text{data} < M+2s^2$ to exclude potential over-statements of FC gaps. The average variance used to screen all 400,000 user-data has limited the pool of "effective figures" that will be used in this study to 211,148 users.

Table 3 Real-world FC data

Model Year	Total vehicle models covered by the effective figure screening of user FC data	% of annual passenger vehicle sales
2008	7749	0.11%
2009	11648	0.11%
2010	17240	0.12%
2011	26470	0.18%
2012	40750	0.26%
2013	71204	0.39%
2014	36087	0.18%
	Total: 21,1148	***Average: 0.20%***

1.3 Real-world and certified FC comparison

The vehicle testing method of FC provides a detailed driving conditions description followed by the test performing entity. There are two potential issues with test driving conditions: (i) Some factors allow for high gaps in test conditions, such as vehicle mileage and outside temperatures, which may result in different FC score for the same vehicle model; (ii) Under real-world circumstances, driving conditions may not be well reflected in the test conditions, mainly given the fact that China is a large country with varying temperatures, topography and urban densities to which averaging does no justice. To date, very limited studies have been conducted to evaluate the representation of real-world conditions in the test requirements for an average driving or by-location driving in China. Given the absence of accountable information, the below table simply highlights loose testing requirements for driving conditions elements that may increase real-world and certified FC gaps.

Table 4 China's type approval cycle requirements – some loose ends may increase real-world and certified FC gaps

	Type-approval
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. FC gaps analyses results and assessment

Between 2008 and 2014, the ratio between reported real-world and certified fuel consumption has increased from 12% to 27%, with an annual average increase of 2.5%. The increase in gap may be a result of data sources quantity and quality variations over time, however it is also likely to be the result of gaps between real-world driving and certification test conditions.

This chapter first examines the difference between real-world and certification fuel consumption based on the methodology presented in the previous chapter. The gap analysis results are introduced from four major perspectives, as described in chapter 2.1. Then, the possible impact of three aspects of driving conditions as a partial explanation to fuel consumption gaps is assessed, as presented in chapter 2.2.

Brand-dependent assessment as source of fuel consumption gap requires a complex analysis that holds driving conditions equal among drivers, and is therefore beyond the scope of this work.

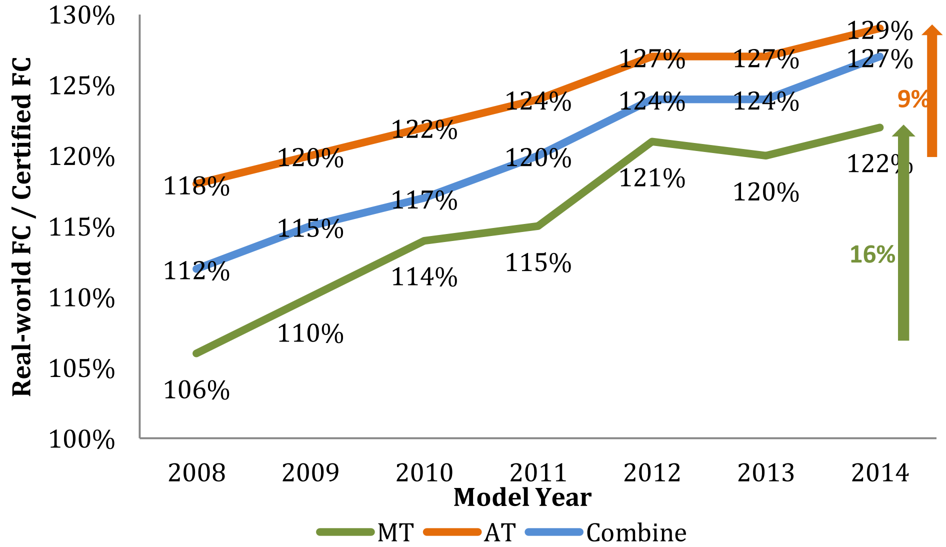
2.1 Analyses results

In this section, the results of the real-world versus certified China passenger vehicle fuel consumption gaps will be presented from four angles: (i) Manual and automated transmission, (ii) Major vehicle segments, (iii) Provinces, (iv) Selected models with extreme FC gaps (top 5 of best and least performing).

2.1.1 By-transmission type FC gap analyses results

As illustrated in Figure 6, between 2008 and 2014, the ratio between reported real-world and certified fuel consumption has increased for both automated and manual transmission passenger vehicles by 11% and 16% respectively. Automated vehicles tend to have higher actual and certified fuel consumption gap than that of manual transmission; however, the difference between types of transmissions has decreased from 12 percentages points in 2008 to 7 percentages points in 2014. Although the majority of vehicles sold in China are manual (58.8% in 2014), the real-world fuel consumption data collected through Bearoil's App is mainly represented by automated transmissions cars (as much as 57.4% of the data sample). For that reason, China's current fuel consumption gap can be well represented through the 27% average gap figure for 2014.

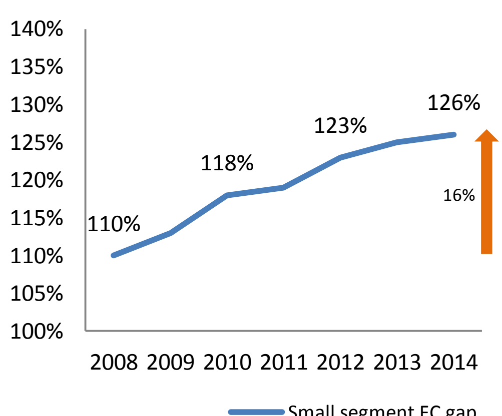
Figure 6: China's 2008-2014 actual vs. real-world FC



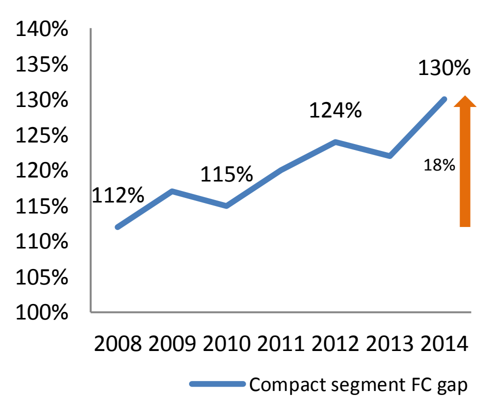
2.1.2 By-segment FC gap analyses results

A by-segment assessment of real-world and certified fuel consumption gaps demonstrates three interesting points: (i) small vehicle types have seen greater increase in gap between 2008 and 2014 - 17% percent on average as oppose to about 8% increase evidenced in larger vehicle types; (ii) Multi-purpose vehicles have the lowest gaps of all other vehicle segments, 17% as oppose to an average of 27%; (iii) SUVs, that have seen the largest sales increase in recent years (34.7% on average between 2012-2014) is the only segment that had undergone a 6 percentage points decrease in gap between 2008 and 2009.

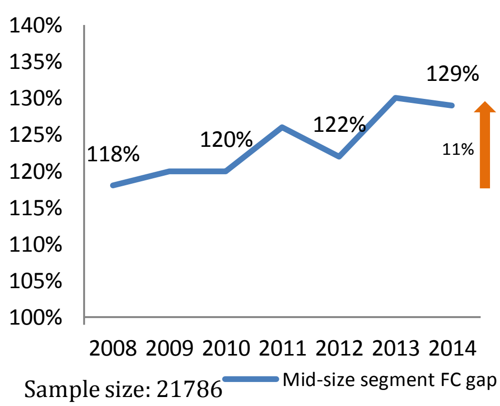
Figure 7: By-segment FC gap analyses results



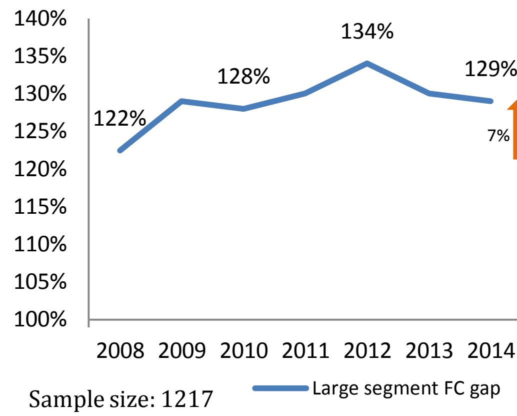
Sample size: 28484
Years: 2008-2014



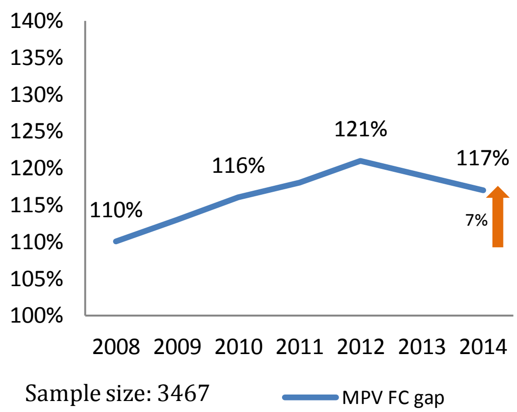
Sample size: 103301
Years: 2008-2014



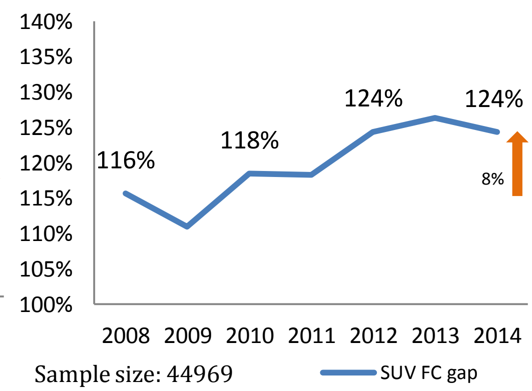
Sample size: 21786
Years: 2008-2014



Sample size: 1217
Years: 2008-2014



Sample size: 3467
Years: 2008-2014



Sample size: 44969
Years:2008-2014

Table 5 By-segment FC gap development

Segment	2008	2009	2010	2011	2012	2013	2014	Average annual FC gap increase	7 years total FC gap increase
Small	110%	113%	118%	119%	123%	125%	126%	2.3%	16%
Compact	112%	117%	115%	120%	124%	122%	130%	2.6%	18%
Mid-size	118%	120%	120%	126%	122%	130%	129%	1.7%	11%
Large	122%	129%	128%	130%	134%	130%	129%	1%	7%
SUV	116%	111%	118%	118%	124%	126%	124%	1.1%	8%
MPV	110%	113%	116%	118%	121%	119%	117%	1%	7%

2.1.3 By-province FC gap analyses results

BearOil App recently added a by-geography feature to its list of data analyses capabilities, namely the Fuel Consumption Index (FCI)[8]. This new feature enables a snapshot of fuel consumption levels for a particular vehicle model at different locations, indicating the by-geography conditions impact on FC differentiation or driving style “areas” (should driving conditions for the compared location be similar).

This study enables (i) an overview of a single model real-world FC compared with the total average and with certified FC (see Figure 8 and Table 6), and (ii) an overview of by-province FC average level compared with the national FC average (see Figure 9). The former demonstrates the high vitality in FC levels for the same car if driven at different provinces, shedding light mainly on the external driving conditions at each province. The *1.6L engine automatic Ford Focus* was selected as it has one of the largest data inputs of the data sample.

The analysis shows that Northern provinces’ FC levels for the Ford Focus are highest, a result that correlates well with these provinces’ low outside temperatures. The high density of Shanghai city may explain why the Ford Focus’ real-world FC levels are relatively high in its territory, despite its convenient geographic features (see Figure 8). While the distance between by-province real-world FC and the average real-world vary by up to 12.3 percentage points, the by-province real world FC is as high as 55 percentage points from the certified FC (see Table 6). When looking solely on the urban test cycle results, the picture looks less grim, with 14 percentage points at most and only 1.5 percentage point gap on average. FC The latter analysis shows that among provinces, Heilongjiang has the largest FC local vs. average real world-certified gap, amounting 109.8%, while Yunnan has the smallest gap of 92.9% (see Figure 9).

[8] http://www.cnautonews.com/qchl/clw/201501/t20150105_340509.htm

Figure 8: Fuel Consumption Index of a Selected Vehicle - Ford Focus 1.6L AT

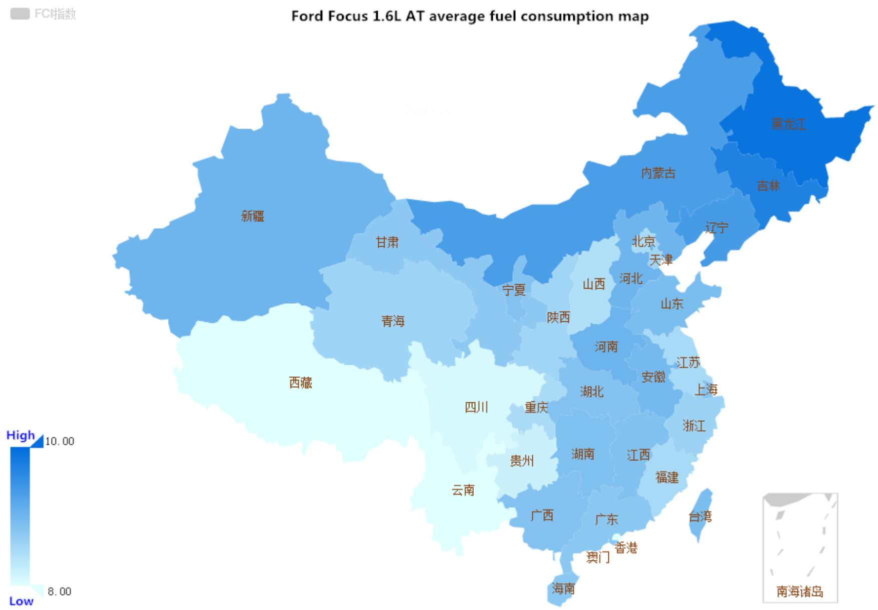
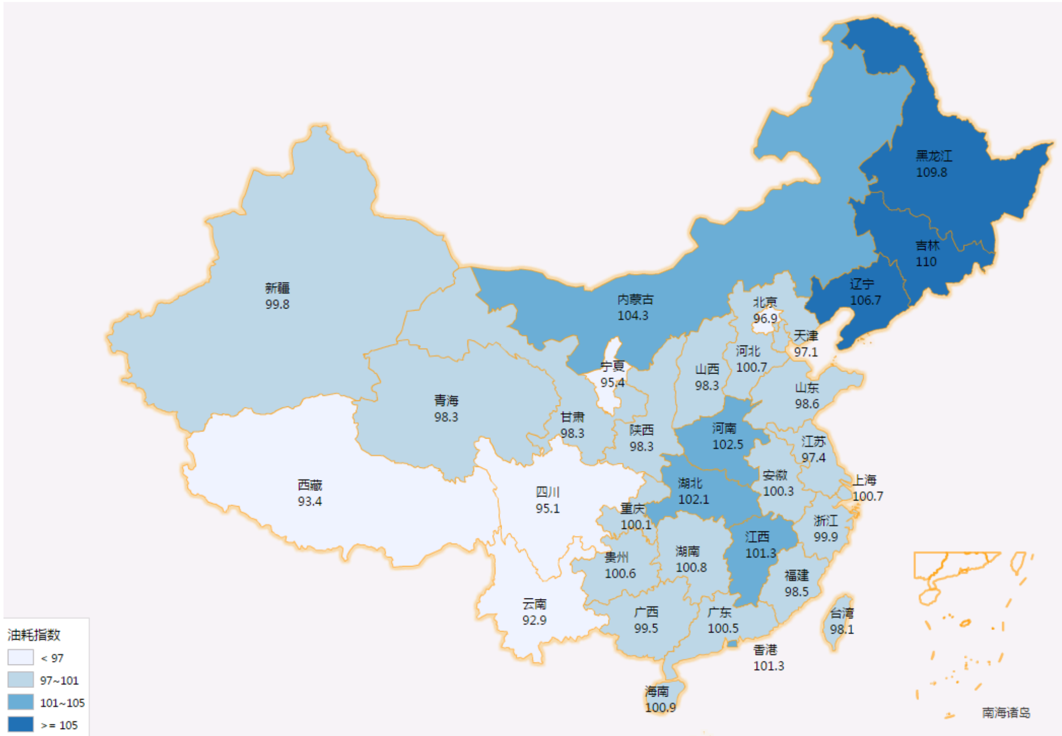


Table 6: Fuel Consumption Data of a Selected Vehicle - Ford Focus 1.6L AT

Province	FC	% of Average FC	% of Certified FC	% of Urban Test FC	Sample Size
Ford Focus 1.6L AT certified FC	6.4		100%		
Heilongjiang	9.92	112.3%	155%	114.0%	49
Jilin	9.71	109.9%	152%	111.6%	44
Liaoning	9.37	106.0%	146%	107.7%	160
Shandong	8.9	100.7%	139%	102.3%	355
Shanghai	8.81	99.7%	138%	101.3%	361
Guangdong	8.78	99.4%	137%	100.9%	906
Zhejiang	8.61	97.4%	135%	99.0%	479
Jiangsu	8.52	96.4%	133%	97.9%	792
Beijing	8.48	96.0%	133%	97.5%	232
Sichuan	8.08	91.4%	126%	92.9%	228
Yunnan	8.02	90.8%	125%	92.2%	69
Total/Average	**8.83**		**138%**	**101.5%**	**3675**

***Red* - Above Baseline FC ; *Green* - Below Baseline FC**

*Figure 9: Fuel Consumption Index – Total Values per Province**



* BearOil App FCI map includes 211,148 user-data inputs; the figure is an average FC at the province out of the national average.

2.1.4 By-model FC gaps

By selecting 16 mainstream models' FC actual results of 1000-2000 units (sample size), this study compares between urban, rural and overall certified FC and actual by-model FC levels: actual fuel consumption differences between models are around 20-35 percentage, urban cycle differences are typically between -10 and 2 percentage, and rural FC levels and actual FC gap is typically ranging 45-65 percentage. It is worth noting that the sample is derived from different drivers and different location and driving conditions in China, which may incur high variations that impact the by-model averages differently between models.

Table 7: By-model FC difference - actual vs. certified, urban and rural FC

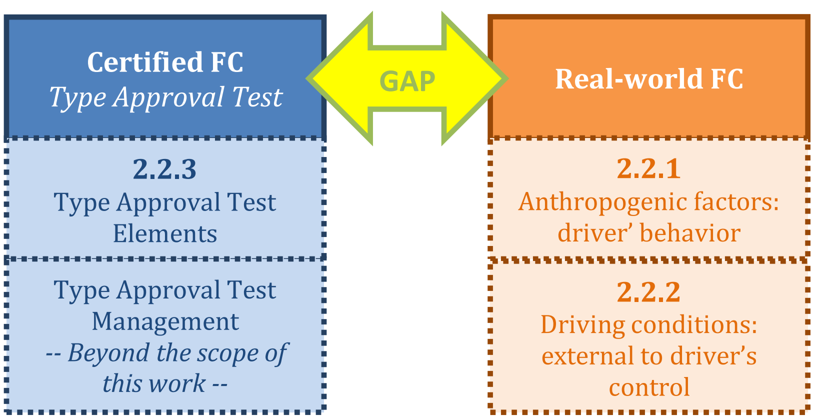
Vehicle type	Actual FC (L/100km)	Sample size (Num)	% of Certified FC	% of Urban Test FC	% of Rural Test FC
1	8.63	2548	34.8%	-0.8%	66.0%
2	8.89	1935	38.9%	2.2%	71.0%
3	7.55	1836	21.8%	-7.9%	54.1%

4	7.80	1230	25.8%	-4.9%	59.2%
5	7.80	2031	30.0%	-1.3%	66.0%
6	7.79	1472	29.8%	-1.4%	65.7%
7	8.43	1015	33.8%	1.6%	65.3%
8	7.85	1005	20.8%	-8.7%	48.1%
9	8.16	1005	29.5%	-1.7%	60.0%
10	9.10	2392	19.7%	-15.0%	56.9%
11	9.70	2326	34.7%	-6.7%	59.0%
12	7.77	1799	25.3%	-1.6%	49.4%
13	12.44	1378	25.7%	-7.2%	59.5%
14	6.68	1106	26.0%	2.8%	45.2%
15	10.60	1099	34.2%	-1.9%	63.1%
16	7.39	1020	23.2%	-4.0%	47.8%
Average		1575	28.4%	-3.5%	58.5%

2.2 Gap assessment

Driving conditions can highly impact ***actual FC*** levels; these can be divided to (i) anthropogenic driving conditions and habits (e.g. acceleration, air conditioning usage, load, tires pressure etc.) and (ii) external driving conditions (road elevation, temperatures, traffic congestion etc.). In the case of ***certified FC***, some elements related to FC testing procedures may reduce the gaps between real-world and certified FC.

Figure 10: Illustration of this chapters' FC gap assessment process



This chapter overviews potential sources for gaps between real-world and certified FC in the case of China, first by highlighting driving conditions – starting from anthropogenic factors and moving to external factors assessment. Then, test conditions elements that can impact the actual-certified FC gap are explored.

The divide of this chapter is meant to provide Chinese drivers with the access to operational information that may improve their fuel consumption and therefore bring immediate air quality improvements and fuel savings – both are crucial elements for China's sustainable development.

2.2.1 Anthropogenic factors: drivers' impact on FC levels

Vehicle technologies that directly or indirectly reduce vehicle fuel consumption have been increasingly incorporated in various vehicles. However some technologies improve vehicle performance during type approval tests and provide the vehicle with better FC certification than during actual driving – various anthropogenic and external driving conditions may offset these FC improvements. For example:

- ***Tire pressure light*** is highly dependent upon the driving's speed and quality of reaction for bringing the intended FC improvement.
- ***Idle-stop systems*** work better at specific geographies and highly dependent upon idling time. It is clear that idle-stop systems are capable of yielding improved fuel economy, with the caveat that public education in fuel-saving vehicle operation is necessary to realize the FC improvement potential of Idle-stop technology. For the Smart, Mazda, Volkwagen vehicle, for example, the percentage differences in fuel economy values between system reached 14.4%, 8.3% and 6.3, respectively[9]
- ***Second gear start*** is in a more efficient region of the BSFC (brake specific fuel consumption). Using a higher gear at acceleration, for example 2nd to 5th gear rather than 1st to 5th gear, can reduce FC by some 6%[10].
- ***Air conditioning*** obviously consumes more energy and therefore reduces fuel consumption. Studies show the impact of air conditioning on fuel consumption can reach 33% increase[11].
- ***Ethanol gasoline*** has lower calorific value compared with pure gasoline, using E10 ethanol gasoline can improve FC by 3%-6%[12].
- ***Charging battery*** during driving will use extra fuel. Starting a drive with a fully charged battery compared with a partially charged battery is of about 1%. State of charge affect the stop/start strategy employed on some vehicles, the engine control system may disable the stop/start strategy if the battery is not sufficiently charged, leading to increased fuel consumption[13].

Anthropogenic factors impacting real-world and certified FC gaps through driving behavior are summarized in the below *Table 8*.

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[9] *Quantifying the effects of Idle-Stop Systems on Fuel Economy in Light-Duty Passenger Vehicles*
http://energy.gov/sites/prod/files/2014/02/f8/idle-stop_light_duty_passenger_vehicles.pdf

[10] *Supporting Analysis regarding Test Procedure Flexibilities and Technology Deployment for Review of the Light Duty Vehicle CO2 Regulations*
http://ec.europa.eu/clima/policies/transport/vehicles/cars/docs/report_2012_en.pdf

[11] https://www.fueleconomy.gov/feg/hotweather.shtml#data-sources

[12] *Fuel Consumption Studies of Spark Ignition Engine Using Blends of Gasoline with Bioethanol*
http://agronomy.emu.ee/vol08Spec1/p08s124.pdf

[13] *Supporting Analysis regarding Test Procedure Flexibilities and Technology Deployment for Review of the Light Duty Vehicle CO2 Regulations*
http://ec.europa.eu/clima/policies/transport/vehicles/cars/docs/report_2012_en.pdf

Table 8: Anthropogenic factors impacting real-world and certified FC gaps – through driving behavior

Anthropogenic factors	Fuel consumption change
Second gear start	Lower
Tires pressure fits recommended levels	Lower
Air-conditioning usage	Higher
Idle-Stop	Lower
Ethanol gasoline	Higher
Charging Battery	Higher

2.2.2 External factors: FC variations beyond drivers' direct control

Various driving conditions, which are beyond the drivers' or test procedure control, impact a vehicle fuel consumption levels. The analysis by-province results demonstrate potential local driving conditions impact on vehicle fuel consumption. This section discusses some the of the fuel consumption gaps likely to be resulted from external driving conditions, as follows:

- ***Cold weather effects*** engine energy discharge and increases transmission friction (mainly due to cold engine oil and other drive-line fluids). It also takes a longer time for an engine to reach the most fuel-efficient temperatures. Typically, rolling resistance and aerodynamic drag increase during the winter winter[14].
- Due to lower throttle frictions at low ***barometric pressures*** (high altitudes), FC decreases. For the case of the EU-NEDC it seems that some 3.6% FC reduction could be achieved when engines works at altitudes above 2200m instead of sea level altitude, while for the case of the US-FTP, a 2.5% in FC reduction was found. At highway speeds, however, FC increase was observed.[15]
- ***Traffic congestion*** slows driving style and increases driving at first gear - and therefore fuel consumption increases. Studies show fuel consumption increase under heavy congestion can reach as much as 40%[16]. For the case of China, the rapid increase in passenger vehicle in recent years (from 65% to 84% private vehicle of total urban fleet between 2004 and 2014) has increased congestion levels significantly.

Table 9: External factors impacting real-world and certified FC gaps

External factors	FC impact	Explanation
Outside temperatures Lower than type approval requirement	Higher	The colder it is the more fuel consuming the engine's work is
Traffic congestion	Higher	The fuel consumption largely depends on

[14] https://www.fueleconomy.gov/feg/coldweather.shtml
[15] http://www.wseas.us/e-library/conferences/2009/vouliagmeni/EELA/EELA-29.pdf
[16] http://docs.trb.org/prp/15-2087.pdf

		the point at which increasing traffic intensities cause flow instabilities
Barometric pressure decreases	Lower	At low barometric pressures (high altitudes) FC decreases in general due to lower throttle frictions

In the case of China, clearly various cities have varying temperatures, barometric pressures and congestion types[17] - impacting FC levels of typically every vehicle segment and model.

Table 10 External factors in China

Annual temperatures below 9°C	Changchun Shenyang Harbin Huhehot Lhasa Xining Lanzhou Urumqi
Annual temperature above 19°C	Chongqing Changsha Nanning Haikou Guangzhou Fuzhou
Barometric pressure below 90KPa	Huhehot Guiyang Lanzhou Xining Yinchuan
Barometric pressure below 70KPa	Lhasa
Speed at peak hour lower than 24km/h	Nanning Jinan Kunming Xian Chongqing Hangzhou Changchun Shenyang Harbin

2.2.3 Varying type approval test elements that may impact FC gaps

There is a technological aspect of a car that is typically beyond the users' control, however this one element has an impactful influence on the models' FC certification score: vehicle mileage. There are potential flexibilities in vehicle mileage in order to achieve the minimum possible friction losses in the engine and vehicle. Analysis of the well-established Ricardo vehicle testing database demonstrates fuel consumption reduction of 5% is possible by extending mileage from 3000km to 15000km[18].

There is one clear external driving condition aspect that is generalized in the Type Test Approval and therefore may result in varying FC results that do not reflect real driving conditions, therefore increasing the FC gap: outside temperature. Theoretically, shifting from an environment with temperatures of 20°C to 30°C is expected to reduce vehicle fuel consumption by 1.7%; Every 1°C decreases is expected to decrease FC by 0.17% (JRC, 2011).[19]

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17 《中国主要城市交通分析报告 2015 Q1》http://trp.autonavi.com/traffic/file/tinfo-2015-Q1.pdf

18 *Supporting Analysis regarding Test Procedure Flexibilities and Technology Deployment for Review of the Light Duty Vehicle CO2 Regulations* http://ec.europa.eu/clima/policies/transport/vehicles/cars/docs/report_2012_en.pdf

19 *Supporting Analysis regarding Test Procedure Flexibilities and Technology Deployment for Review of the Light Duty Vehicle CO2 Regulations*http://ec.europa.eu/clima/policies/transport/vehicles/cars/docs/report_2012_en.pdf

Table 11: Anthropogenic factors impacting real-world and certified FC gaps – through certification requirements

Vehicle-related factors	Type Approval Test requirement range	FC impact range
Vehicle reaches high mileage	3k-15k m	5%
Test temperature	20-30°	1.7%

3. Conclusion and suggestion

Assessing the real-world and certified FC gaps and their sources is a challenging task, particularly in the case of China: there are limited supporting studies that can scientifically suggest ranges of FC gaps per driving condition, in a certain geography as well as on average; China's test cycle allows for flexibilities that may vary FC outcomes between vehicles and may not represent typical Chinese driving (at least not at all locations) due to its conformity with EU driving (NEDC); real-world FC data is scarce and both certified and real-world data is in some cases doubtable, due to testing management issues and voluntary inputs by random drivers, respectively. That said, the analysis performed in this study, through collaboration between BearOil App and *i*CET, introduces a novel attempt to provide stakeholders with some insights that could hereafter be more thoroughly studied.

This study found that:

- Between 2008 and 2014 the ratio between reported real-world and certified fuel consumption has increased for both automated and manual transmission passenger vehicles by 11% and 16% respectively. The difference between type of transmissions have decreased from 12 percentages points in 2008 to 7 percentages points in 2014, yet automated vehicles still have a larger FC gap;
- Multi-purpose vehicles have the lowest gaps of all other vehicle segments, 17% as oppose to an average of 27%;
- The small vehicle segment have seen greater increase in gap between 2008 and 2014 - 17% percent on average as oppose to about 8% increase evidenced in larger vehicle types;
- SUVs, that have seen the largest sales increase in recent years (34.7% on average between 2012-2014), is the only segment that has undergone a 6 percentage points decrease in gap between 2008 and 2009.
- Among provinces, Heilongjiang has the largest FC local vs. Average real world-certified gap, amounting 109.8%, while Yunnan has the smallest gap of 92.9%.
- The average FC gap of all brands was 122.7%, while the best performing brand (Baojun) achieved 114% and the least performing brand (BMW) scored 133%.
- Good driving habits can reduce fuel consumption; fuel consumption variations reach a gap of as much as 26%.
- Through analysis of selected models it is evidenced that urban driving cycle test FC results better represent actual driving FC; It may be that rural driving results contribute little if any to the evaluation of real world FC on the test cycle – suggesting that rural

driving portion of the test may need to be reduced for better representing real-world driving.

As China is faced with a challenging average annual fuel consumption level of 5L/100km by 2020, and given last years' non-compliance from as many as 17 vehicle companies, FC monitoring is important. China's recent declarations of urban air quality improvements could promote effective implementation efforts should existing policy tools such as FC would be linked to GHG emissions and air quality. Furthermore, by demonstrating anthropogenic FC impacts, drivers could internalize the governments' call for public participation in the effort to combat air pollution and improve China's sustainable lifestyle, as well as reducing their fuel expenses. By highlighting FC certification issues, decision-makers may be inspired to re-examine FC certification process in an attempt to reduce real-world and certification FC gaps.

Appendix I

Brand	FC gap	Sample size
BMW	138.7%	1513
AUDI	132.8%	1786
HAVAL	131.6%	6229
GEELY	129.3%	2837
MG	128.4%	2169
BYD	128.3%	5206
PEGUGEOT	128.1%	6986
FORD	127.3%	24333
CHANGAN	126.7%	6241
GREATWALL	126.3%	6948
HYUNDAI	125.2%	9411
CITROEN	124.3%	4028
KIA	124.2%	5815
HAIMA	123.3%	1375
BENTENG	122.8%	1426
MAZDA	122.8%	6221
CHEVROLET	122.5%	11864
TOYOTA	121.6%	13313
BUICK	121.5%	10641
HONDA	121.3%	7890
NISSIAN	118.3%	11143
ROWE	118.3%	2564
VW	117.9%	22587
Mitsubishi	117.4%	1995
CHERY	117.2%	9292
BRILLIANCE	116.5%	1055
SKODA	115.1%	7955
SUZUKI	114.9%	5299
BAOJUN	114.4%	1087
Average	122.7%	199209