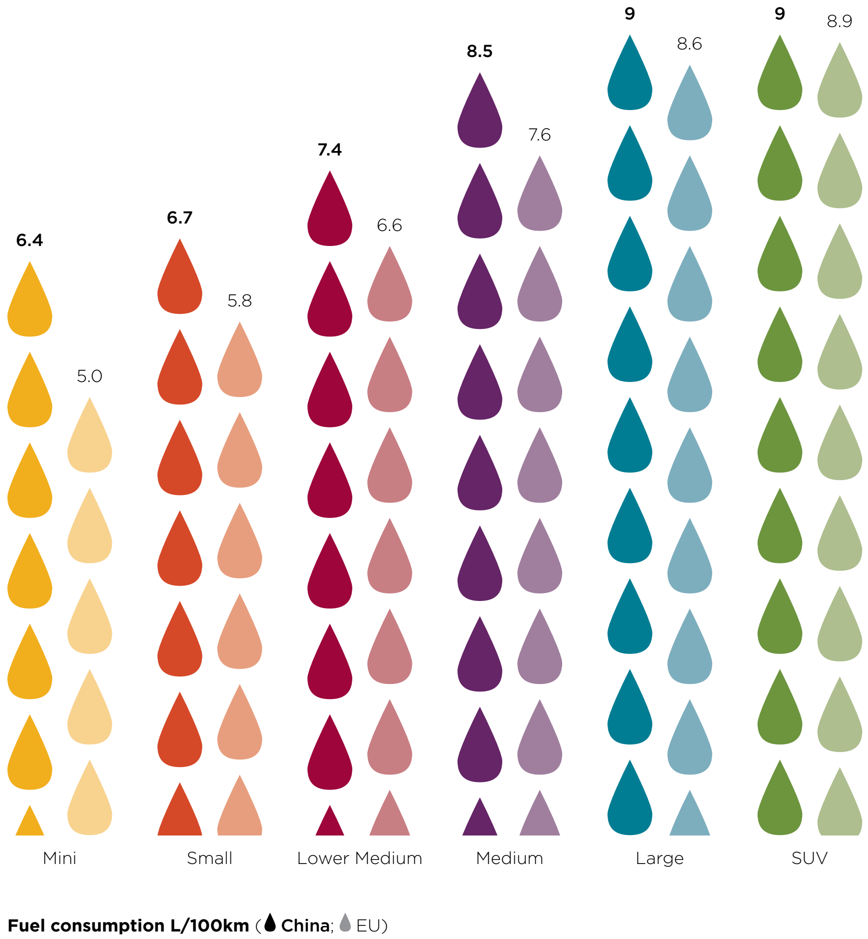
THE NEW PASSENGER CAR FLEET IN CHINA, 2010

Technology Assessment and International Comparisons



THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

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1 EXECUTIVE SUMMARY

With an incredible 26% annual average growth rate of vehicle production over the past decade, China has become the world's largest new car market. But the rapid growth in automobile use has also put increasing pressure on the nation's goals of oil independence and climate change mitigation. Realizing these challenges, China introduced two phases of vehicle fuel consumption regulations for light-duty vehicles in 2005, and is planning to implement the third phase by the end of 2015.

In addition to dramatically reducing the fleet's fuel consumption, these increasingly tightened standards also aim at upgrading China's auto industry with world-class vehicle efficiency technologies, and shortening its technological gap from traditionally motorized countries and regions such as the United States and the European Union. Moving forward, China's recently released long-term auto industry development plan explicitly emphasized the importance of modernizing the fleet by developing more efficient and cleaner vehicles.

In this context, this paper analyzes the status of fuel efficiency technology adoption of the current Chinese new passenger car fleet, focusing on the differences among major car market segments, between Chinese independent automakers and joint venture manufacturers, and between domestically produced and import fleets. This paper also compares side-by-side the status of technology application across the Chinese, EU, and US car fleets. Its findings, as listed below, provide insights on how to improve current car fuel consumption regulations and develop future standards.

- Major vehicle specifications such as engine displacement, curb weight (also commonly rendered as "kerb weight," the British spelling), footprint, and power are in between the levels of the US and EU car fleets (excluding diesel cars). Given the average size of the vehicles (9% heavier and 1% bigger than the EU car fleet, and 21% lighter and 10% smaller than the US car fleet), the Chinese fleet is less fuel-efficient than those of the other two regions (26% more fuel-consumptive than the EU car fleet and only 4% less fuel-consumptive than the US car fleet). China lags significantly behind either one of or both the EU and US in terms of most major efficiency technologies, including variable valve timing, direct gasoline injection, turbocharging and supercharging, though it is catching up on the application of certain technologies such as dual clutch transmission (with a similar adoption rate as that of the US). These findings are summarized in Table 1.1 and detailed in Section 5.

Parameters	EU PC Fleet[a]	EU Gasoline PC Fleet[a]	US LDV Fleet[b]	US PC Fleet[b]	Chinese PC Fleet
Basic Specifications					
Engine size (L)	1.6	1.4	3.1	2.6	1.7
Curb weight (kg)	1,322	1,172	1,815	1,611	1,280
Footprint (m^2)	3.90	3.75	4.51	4.22	3.79
Utility					
Power (kW)	84	77	174[c]	156[c]	86
Max speed (km/h)	185	178	223	218	170
Power-to-weight ratio (W/kg)	62	63	96	97	65
Engine specific power (kW/L)	51	52	57	60	51
Fuel Consumption and CO_2					
Urban FC (L/100 km)[e]	7.4	8.1	9.8	8.6	10.4
Extra-urban FC (L/100 km)[e]	4.9	5.1	6.4	5.6	6.3
Combined FC (L/100 km)[e]	5.8	6.2	8.3	7.3	7.8
Combined NEDC FC (L/100 km)	5.8	6.2	9.4	8.1	7.8
CO_2 (combined)[f]	143	145	195	171	183
Technology Adoption					
Fuel Type					
CNG/LPG/flexible-fuel	3%	-	-	-	0%
Diesel	51%	-	1%	1%	1%
Unleaded gasoline	44%	100%	96%	94%	99%
Hybrid: unleaded gasoline/electric	1%	-	4%	5%	<1%
Transmission					
Automatic	9%	14%	84%	80%	34%
CVT	2%	1%	11%	14%	5%
DCT	3%	-	1%[d]	2%[d]	1%
Manual	86%	83%	4%	5%	60%
Number of Gears					
≤ 4	1%	2%	25%	29%	12%
5	59%	51%	24%	21%	66%
≥ 6	38%	17%	41%	36%	17%
Fuel Supply					
Carburetor	-	-	0%	0%	<1%
Diesel injection	-	-	1%	1%	<1%
Gasoline direct injection	14%	32%	8%	8%	6%
Multipoint injection	-	-	77%	80%	82%
Single-point injection	-	-	0%	0%	11%
Sequential fuel injection	-	-	14%	11%	0%
Air Intake					
Naturally aspirated	41%	80%	-	-	93%
Turbocharged or supercharged	59%	16%	4%	4%	7%
Variable Valve Timing	-	-	84%	91%	44%
Variable Valve Lift					
Continuous VVL	-	-	2%	2%	1%
Discrete VVL	-	-	15%	16%	5%

Notes:

a Source: ICCT EU database and ICCT European Vehicle Market Statistics: 2011 Pocketbook (Campestrini, M., & Mock, P., 2011)

b Source: EPA 2011 and 2010 Trends Reports

c The US values are reported as net power, which is different from China's rated power. Based on GB 7258-2004, US values were converted to rated power.

d Automatic without lockup from 2011 EPA trends report is assumed to be DCT.

e Fuel consumption: Region-specific test cycle used; for US data, lab data rather than adjusted data used.

f CO_2 data: Region specific test cycle used; for US, raw FTP and HWY lab data rather than adjust values in 2011 EPA Trends report was used; for China, the whole fleet was assumed to run on gasoline for CO_2 calculation.

Table 1.1

Comparison of fleet average characteristics and technology applications across EU, US, and Chinese car fleets, 2010

- Import cars, as a small fraction of the total market, were mainly large, high-performance, luxury, and gas-guzzling vehicles. Nearly half of the import fleet was fuel-consumptive SUVs. Overall, more advanced engine and transmission technologies were found in the import fleet, but they were used to boost performance rather than fuel economy. A detailed technological comparison of China's import and domestic fleets can be found in Section 6.

- The Chinese mini-to-large-car segments are quite similar to their counterparts in the EU in terms of key vehicle specifications (see Table 1.2). Despite the similarities in vehicle specifications, average CO_2 emissions rates (and fuel consumption rates) of typical cars for each segment in China are all higher, to various extents, than the corresponding cars in Europe. In particular, the CO_2 emissions rate of an average Chinese car is 11% higher than that of a typical car in Europe (173 g/km vs. 156 g/km), mainly due to the technology lag in the Chinese fleet. Detailed comparison on technologies between the Chinese and EU segments is included in Section 4.

EU 2010 data for EU-27

Segment	Mini-cars		Small		Lower medium		Medium		Upper medium		Off-road		Car-derived vans	
Market share	11%		29%		32%		11%		3%		9%		2%	
Representative model	Peugeot 107		Toyota Yaris		Volkswagen Golf		Toyota Avensis		BMW 5er series		BMW X3		Renault Kangoo	
Diesel share	7%		35%		59%		78%		81%		76%		77%	
	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel
Cylinder	3.6	3.8	3.9	3.9	4.0	4.0	4.3	4.1	5.2	5.0	4.2	4.4	4.0	4.0
Displacement [L]	1.1	1.2	1.3	1.4	1.5	1.7	2.0	2.0	2.7	2.5	1.9	2.2	1.5	1.6
Power [kW]	51	51	63	61	87	83	128	109	177	144	111	123	68	67
Auto. transmission share	12%	12%	9%	3%	14%	12%	36%	21%	74%	61%	24%	37%	4%	4%
Curb weight [kg]	904	975	1105	1173	1312	1405	1514	1565	1708	1764	1450	1772	1402	1428
CO_2 [g/km] (NEDC)	118	111	136	113	156	132	178	148	200	163	182	182	178	144

China 2010 passenger car data

Segment	Mini	Small	Lower medium	Medium	Large	SUV	Minivan
Market share	6%	15%	32%	10%	4%	10%	16%
Representative model	Chery QQ3	BYD F3	Hyundai Elantra	Honda Accord	Audi A6	Honda CR-V	Wuling Zhiguang
Diesel share	0%	0%	0%	0%	1%	6%	0%
Cylinder	3.5	3.9	4.0	4.1	5.0	4.1	4.0
Displacement [L]	1.1	1.4	1.6	2.0	2.4	2.1	1.1
Power [kW]	50	71	84	112	141	110	45
Auto. transmission share	17%	26%	44%	67%	89%	50%	0%
Curb weight [kg]	918	1080	1258	1464	1684	1567	998
CO_2 [g/km] (NEDC)	150	157	173	199	211	211	178

Note: Though a representative car model is given for each segment, the data are the sales-weighted averages for relevant parameters; unlike the EU segments that separate diesel and gasoline, the data values of China's segments are based on all available fuel types because gasoline is the dominant fuel across all segments.

Table 1.2

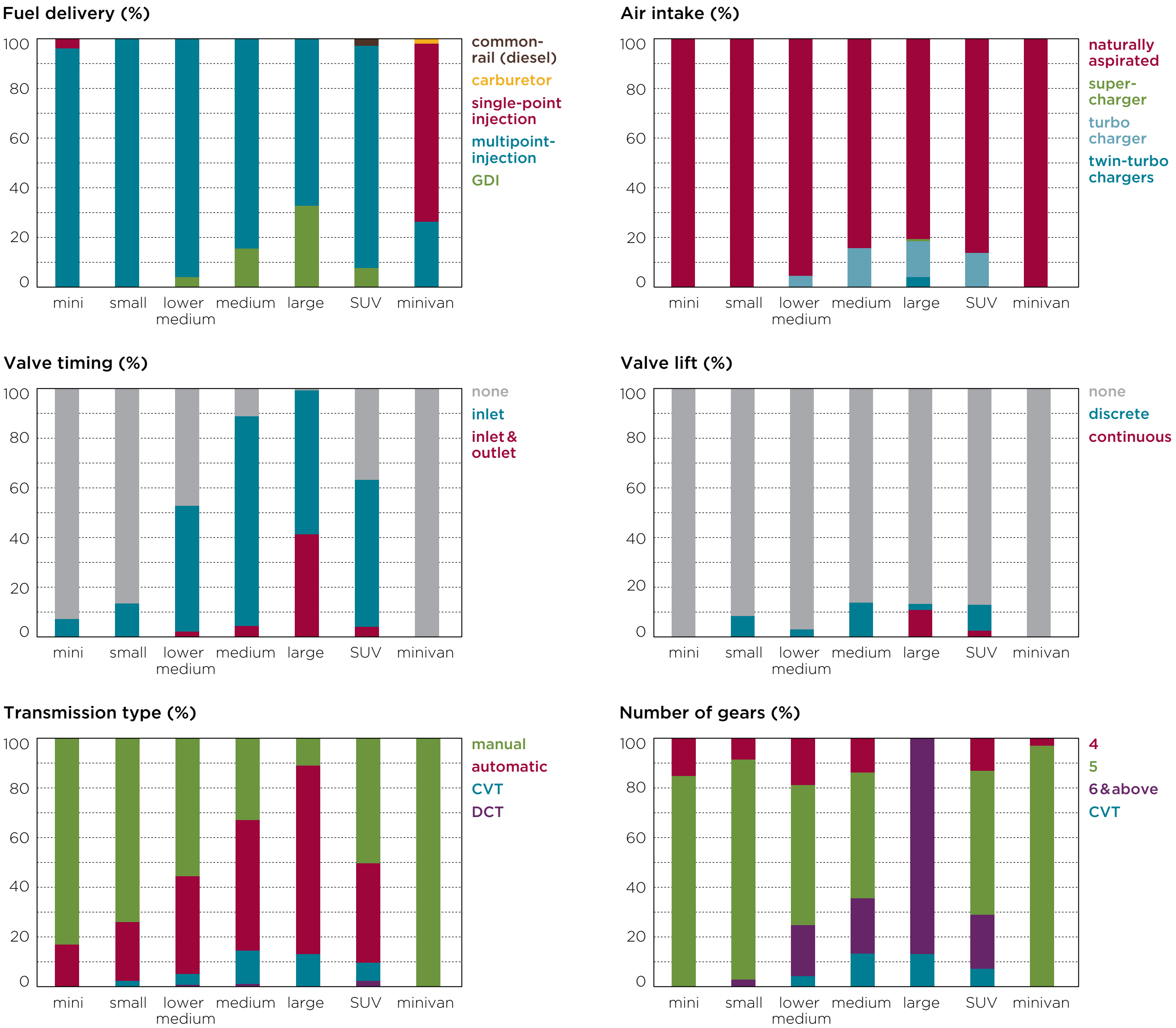
Illustration of representative models and comparison of key average vehicle features in China and EU by segment

- Technology application levels vary from segment to segment. In general, smaller-car segments, dominated by Chinese independent brands, lag behind on almost all efficiency technologies compared to larger-car segments, which are dominated by automaker joint ventures (see Figure 1.3).

- Minivans are a unique car segment in China and a few other developing countries. These vehicles are built on minicar platforms, but are taller and with greater inside volume than minicars for carrying either goods or passengers in suburban and rural areas. Typical Chinese minivans (e.g. the Wuling Zhiguang, with a 1-liter engine and about 1,000 kg curb weight) are smaller, lighter, and less powerful than minivans in the US market (e.g. the Honda Odyssey, with a 3.5-L engine and over 2,000 kg curb weight) or so-called car-derived vans in the EU market (e.g. the Renault Kangoo, with a 1.5-L engine and 1,400 kg curb weight). Despite their small size, the fuel efficiency of these vehicles is poor, comparable to a typical mid-sized car. This is partially due to the design features of the vehicles, which are tailored to a particular use. On the other hand, to keep their sticker prices very low, very few manufacturers equip minivans with advanced engine and transmission technologies.

Figure 1.3

Engine and transmission technology application by segment



- Data from 18 major domestic manufacturers that represent more than 80% of the 2010 car market shows that Chinese independent automakers produce smaller-sized cars than do most joint ventures. However, their fleet-average fuel consumption performance may not be better than that of many joint ventures manufacturing larger cars (Figure 1.4).

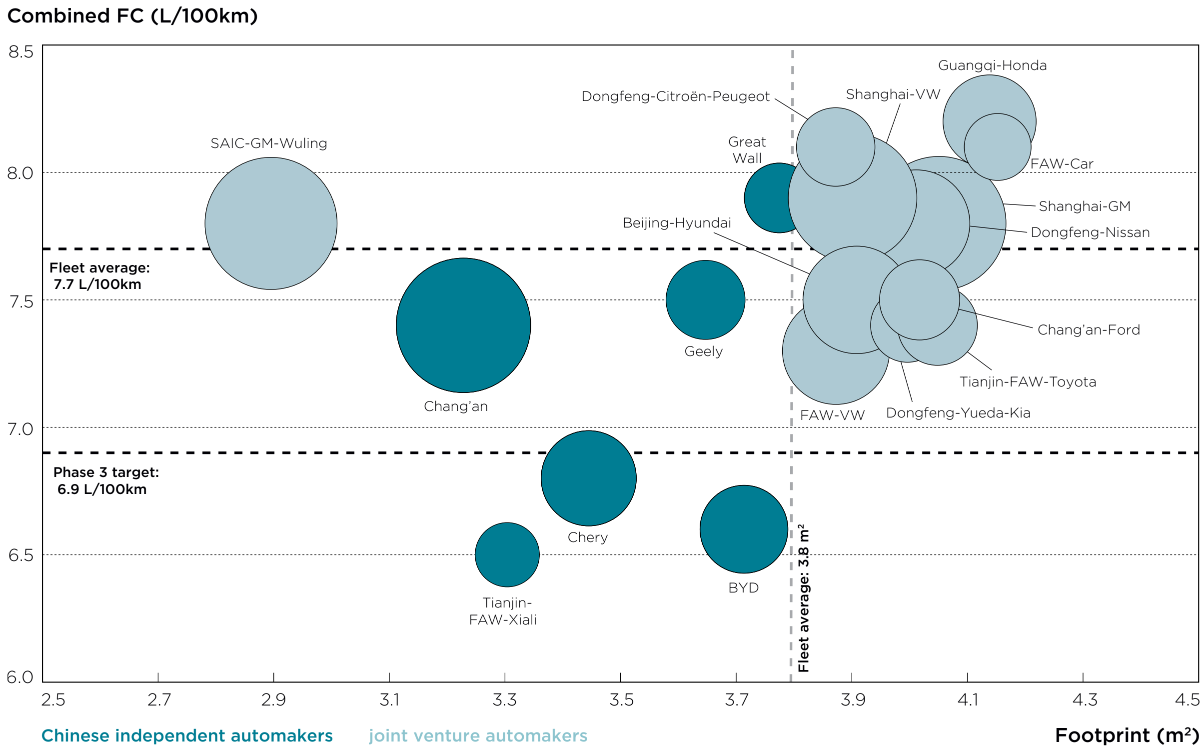


Figure 1.4

Corporate-average fuel consumption rates as a function of corporate-average vehicle footprint of major manufacturers

- There is a clear gap in efficiency technology application between Chinese independent automakers and joint venture automakers. Many engine technologies commonly used by joint ventures, such as variable valve timing, are still in the early development stage among Chinese independent automakers (Figure 1.5). A detailed case study in Section 7 that compares a Chinese independent brand (Geely) with a US brand (Chevrolet) and a European brand (Volkswagen) with similar market orientation to Geely provides additional evidence of our observations in technological differences between the two groups of manufacturers.

Figure 1.5

Technology application by major manufacturers grouped into Chinese independent automakers and joint venture automakers

Based on the above general findings, we offer the following preliminary policy recommendations for the development of regulations governing passenger car fuel consumption.

– Stringent regulatory standards are needed to drive technology innovation and upgrades, enhancing the competitiveness of the Chinese auto industry.

– The current policy (or lack of effective policy) on fuel consumption of import cars has failed to bring vehicles with world-class efficiency onto the Chinese market. Future regulations should apply the same set of noncompliance penalties used for domestic vehicles to imports as well. Special incentives that encourage the importation of super-efficient vehicles can be considered.

– Given that the advanced technologies in large-car segments are more market-ready, future standards can be designed to be more stringent on bigger and heavier vehicles than on small cars.

– Special incentives are needed to improve the efficiency of minivans or to replace the segment with more efficient and similarly functional vehicles.

– Flexibility and incentives may be needed to allow some Chinese automakers that are behind on technologies and have relatively narrow product lines to be able to meet the future stringent standards within a reasonable range of cost increases.

2 INTRODUCTION

2.1 Background

China, the world's largest auto market for three years in a row since 2009, produced more the 18.5 million automobiles in 2011.[1] As the economy has bloomed, with double-digit annual GDP growth rates for the past decade,[2] private cars have become more and more affordable to average Chinese households. More than 13.7 million passenger cars were sold in 2010, three-quarters of the total vehicle sales in that year.[3] As a result, the passenger car sector became an increasingly significant contributor to the nation's transportation fuel consumption, worsened urban air quality, and congestion in many large cities.

Facing the increasing pressure on the nation's goals of oil independence and climate change mitigation, China adopted a series of regulations to curb cars' fuel consumption. For passenger cars,[4] China developed two phases of fuel consumption standards (GB 19578-2004) in 2004, rolling out Phase 1 starting in 2005 and Phase 2 in 2008.[5] At the end of 2011, China's Ministry of Industry and Information Technology (MIIT) put into place its third phase of passenger car fuel consumption standards (GB27999-2011). When fully implemented in 2015, the regulation is supposed to drive down the fleet-average fuel consumption rate of new passenger cars from the current 7.8 liters per hundred kilometers (L / 100 km) to 6.9 L/100 km.[6] Similar to the previous regulations, the Phase 3 standard curves are set based on vehicle curb weight classes, with separate curves for regular cars and special-featured cars (vehicles with three or more rows of seating, off-road vehicles or SUVs, and vehicles with automatic transmissions). However, the Phase 3 standards established corporate average fuel consumption (CAFC) targets for automakers selling cars in China, compared to the per-vehicle limits adopted in the previous standards. Figure 2.1 depicts the stringency levels of all three phases of standards.

The design of the first two phases of standards was intended to eliminate vehicles with the most outdated technologies from the market.[7] However, the upcoming and future regulations will focus on driving technology innovation.[8] The MIIT's newly released Energy-Saving and New Energy Vehicle Industrial Development Plan, 2012–2020, sets a preliminary fleet-average fuel consumption target of 5 L/100 km for new passenger cars by 2020. The Plan also explicitly emphasized that the key strategy of China's auto industry for the rest of the decade is to upgrade domestic automakers with world-class efficiency and clean-vehicle technologies, thus lifting the overall competitiveness of China's auto industry.[9]

1 Ward's Automotive Group, 2009–2011 World Vehicle Sales (customized data for the ICCT).

2 "China's average annual GDP growth rate reached 10.7% for the past decade (in Chinese)," Caijing News, June 25, 2012, retrieved from http://economy.caijing.com.cn/2012-06-25/111909157.html

3 China Association of Automobile Manufacturers, 2011 China Automotive Industry Yearbook, p467.

4 Passenger cars, by regulatory definition, are light-duty vehicles intended to carry passengers and with curb weight of no more than 3,500 kg and fewer than nine seats.

5 Ministry of Industry and Information Technology, "Limit of Fuel Consumption For Passenger Cars" (GB19578-2004). Retrieved from http://www.miit.gov.cn/n11293472/n11293832/n11294282/n14295512.files/n14295511.pdf. The Phase 1 standards were implemented in 2005 for newly certified passenger car models, and in 2006 for continued models. The Phase 2 standards were implemented in 2008 for newly certified models, and in 2009 for continued models.

6 Source of 2015 (Phase 3) fleet-average target: State Council Announcement No. 2012–22, "Energy Saving and New Energy Vehicle Industrial Development Plan 2012–2020 (节能与新能源汽车产业发展规划 2012–2020)," June 28, 2012. Retrieved from http://www.gov.cn/zwgk/2012-07/09/content_2179032.htm.

7 Explanation to the Limit of Fuel Consumption For Passenger Cars (Phase 1 and Phase 2), Section 5.2, p3.

8 Explanation to the Limit of Fuel Consumption For Passenger Cars (Phase 3), p1.

9 The State Council of the People's Republic of China, Announcement No, 2012–22, Energy-Saving and New-Energy Vehicle Industrial Development Plan. Retrieved from http://www.gov.cn/zwgk/2012-07/09/content_2179032.htm.

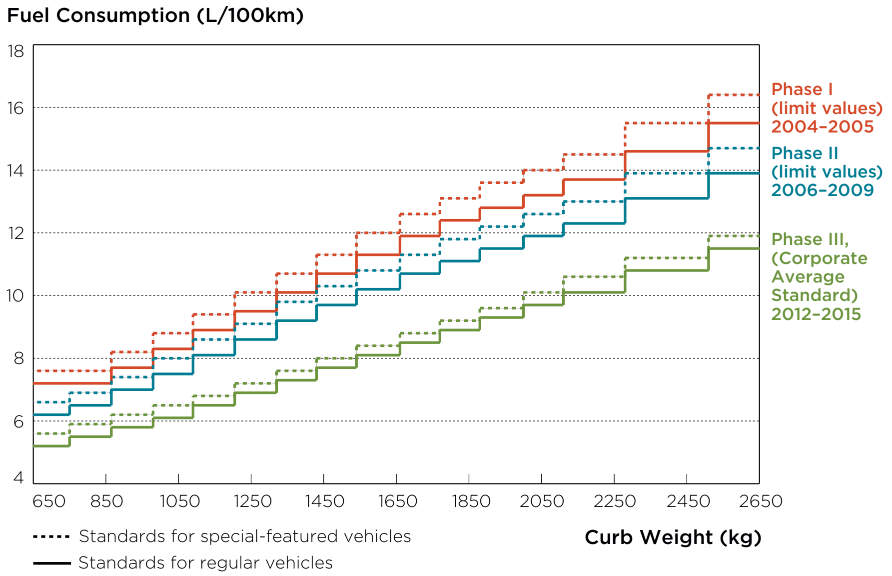


Figure 2.1

Illustration of Chinese Phase 1, 2, and 3 fuel consumption standards for passenger cars

2.2 Objectives

In this context, this paper analyzes the status of fuel-efficiency technology adoption of the current Chinese new passenger car fleet, focusing on the comparisons among major car market segments, between Chinese independent automakers and joint venture manufacturers, and between domestically produced and import fleets. This paper also makes a side-by-side comparison of technology application across the Chinese, EU, and US car fleets. Findings may provide insight into key questions related to the improvement of current car fuel consumption regulations and development of future standards. These key questions include:

- Do Chinese passenger cars lag in terms of fuel-saving technologies from cars in the US and EU, considering the difference in vehicle size, weight, and other major characteristics across the regions? And if so, how far behind is the Chinese fleet?
- Do import cars adopt more fuel-saving technologies and are they more efficient than domestically produced cars?
- What is the technology adoption status of each major market segment and each domestic manufacturer? How do they compare to each other on technology adoption?
- How different are independent brands from joint venture automakers in terms of technology adoption?

2.3 Existing literature and added value of this report

There are a few recent literature relevant to this topic, including the China Automotive Technology and Research Center's paper "China Vehicle Fuel Consumption and Technology Condition Report" (CATARC, 2011), released to a limited audience in November 2011; "China Passenger Car Vehicle Corporate Average Fuel Consumption Trend Report of 2011" (Ma et al., 2012), published by the Innovation Center for Energy and Transportation in June 2012; "Comparisons of Vehicle Technology and Fuel Efficiency Across 10 Countries" (Duleep, 2011), a draft final report by the International Energy Agency released in December 2011; and "International Comparison of Light-duty Vehicle Fuel Economy and Related Characteristics," (Cuenot and Fulton, 2011), published by the Global Fuel Economy Initiative in 2011.

Each of these papers had its own focus and employed different analytical approaches. CATARC (2011) analyzed distribution of key vehicle characteristics and technology adoption status at the aggregated fleet level, but did not involve analysis at the manufacturer level, and all technology adoption rate data were calculated based on number of vehicle models instead of their sales volume. Ma et al. (2012) aimed to calculate and rank the corporate average (sales-weighted) fuel consumption rates of major auto groups and manufacturers and did not involve analysis of vehicle technologies. Compared with the first two papers, which focused narrowly on the Chinese car market, Duleep (2011) and Cuenot and Fulton (2011) involved multi-regional analysis and comparisons on key vehicle characteristics, vehicle fuel consumption, and CO_2 emissions rate, as well as certain efficiency technologies. Both reports adopted sales-weighted averaging when computing fleet-average vehicle characteristic values, fuel consumption/CO_2 emissions rates, and market share of vehicles equipped with certain technologies. And both reports conducted the above-mentioned analysis only to the aggregated country or region level.

This report focuses on the Chinese car market but also compares it in detail to two other large vehicle markets – the US and EU – in terms of vehicle characteristics and a wide range of engine and transmission technologies. Vehicle attributes and technical parameters analyzed in this report include:

- Engine displacement
- Vehicle curb weight
- Vehicle dimensions, including length, width, height, wheelbase length, front and rear track width, and vehicle footprint (area defined by the four wheels of a vehicle)
- Engine power
- Torque
- Maximum speed
- Power to weight ratio
- Specific power (ratio between power and displacement)
- Fuel consumption rates under NEDC urban, extra-urban and combined test cycles
- Fuel type
- Transmission type and gear count
- Fuel supply system
- Air intake system
- Valve timing and lift technology
- Drivetrain technology

We based our study on a current, comprehensive Chinese light-duty vehicle database, compiled by an independent data provider, that includes model-by-model information on vehicle features and technologies, official fuel consumption rates tested on regulatory test cycles, and sales volumes. This comprehensive database allows us to 1) conduct sales-weighted averaging analyses on all the above parameters, 2) analyze from the more aggregated fleet level to the more detailed segment and manufacturer levels, 3) find the differences among various regions, among vehicles of different origins, between joint venture automakers and Chinese independent brands, and even among each individual manufacturer. This level of analysis makes this report a unique contribution to the existing literature, offering an in-depth understanding of China's car market and auto manufacturers.

2.4 Organization

Section 3 of this paper describes our data source, coverage, and completeness, serving as a foundation by which reviewers can understand the analytical data in the following sections. Section 4 analyzes vehicle features and fuel efficiency technology application levels of the domestic fleet by major car market segment. Section 5 compares fleet-average vehicle features and technology adoption across the Chinese, US, and EU light-duty vehicle fleets. Section 6 compares vehicle features and technology adoption between domestically produced and import cars. Section 7 analyzes corporate-average vehicle features and technology adoption rates of each major domestic manufacturer, focusing on differences between Chinese independent automakers and joint venture car companies. Finally, Section 8 summarizes the findings from each section and provides preliminary policy recommendations.

3 DATA DESCRIPTION

The analysis of this paper is based on data from the following sources:

- China 2010 passenger car database provided by Segment Y[10]
- EU-27 2010 passenger car database compiled by the ICCT (Campestrini & Mock, 2011)
- US MY 2010 database
- US EPA trends report (US EPA, 2011; US EPA, 2012)

10 Segment Y Automotive Intelligence Pvt. Ltd. (www.segmenty.com) is an India-based company with a focus on the Asian automotive market.

Overall, the raw database for China's fleet provides good quality in terms of data availability, except for a few parameters mentioned below. Table 3.1 shows the data availability for the overall Chinese passenger car fleet, then a breakdown between the domestic and import fleets and each major market segment within the domestic fleet. Vehicle specifications and types of vehicle efficiency technologies included in our analysis are listed in the left-hand column, and the fill-in rate by sales for each parameter and for each vehicle segment is listed in the right-hand columns. We considered a 75% fill-in rate or above as good quality that should yield meaningful results. One relatively poor fill-in rate was seen in the data on 0–100 km/h acceleration time for all classes. For this reason, power-to-weight ratio values were selected as an alternative to reflect performance. For parameters with missing values, as mentioned above, data analysis was based on the available values in the raw database.

	PC Fleet (All values in percent)			Domestic						
Parameters		**Import Fleet**	**Domestic Fleet**	**Mini**	**Small**	**Lower medium**	**Medium**	**Large**	**SUV**	**Minivan**
Engine size (cc)	100	100	100	100	100	100	100	100	100	100
Curb weight (kg)	100	100	100	100	100	100	100	100	100	100
Wheel base (mm)	100	100	100	100	100	100	100	100	100	99
Front track width (mm)	100	100	100	100	100	100	99	100	100	98
Rear track width (mm)	100	100	100	100	100	100	99	100	100	98
Power (HP)	100	100	100	100	100	100	100	100	98	100
HP (rpm)	100	100	100	100	100	100	100	100	100	99
Torque (N.m)	100	100	100	100	100	100	99	100	100	100
Torque (rpm)	100	100	100	100	100	100	99	100	100	99
Max speed (km/h)	99	97	99	100	100	100	99	100	98	98
Acceleration speed 0–100 km/h	**34**	84	**32**	**16**	**27**	**41**	**59**	**70**	**26**	**0**
Compression ratio	94	99	93	84	99	98	84	96	77	100
Drive train	100	100	100	100	100	100	100	100	100	100
Fuel type	100	100	100	100	100	100	100	100	100	100
Transmission type	100	100	100	100	100	100	100	100	100	100
Number of gears	100	100	100	100	100	100	100	100	100	100
Engine type	100	100	100	100	100	100	100	100	100	100
Valve configuration	100	100	100	100	100	100	100	100	100	100
Number of cylinders	100	100	100	100	100	100	100	100	100	100
Valve per cylinder	100	100	100	100	100	100	100	100	100	100
Fuel supply	100	100	100	100	100	100	100	100	100	100
Air intake	100	100	100	100	100	100	100	100	100	100
Valve timing	100	100	100	100	100	100	100	100	100	100
Valve lift	100	100	100	100	100	100	100	100	100	100
Fuel consumption (urban)	100	100	100	100	100	100	100	100	100	100
Fuel consumption (extra-urban)	100	100	100	100	100	100	100	100	100	100
Fuel consumption (combined)	100	100	100	100	100	100	100	100	100	100
Emissions standard	100	100	100	100	100	100	100	100	100	100

0–24%
25–49%
50–74%
75–100%

Table 3.1

Data availability of key parameters by segment

4 TECHNOLOGY ADOPTION BY VEHICLE MARKET SEGMENT

This section analyzes fleet features and fuel efficiency technology application levels of the domestic fleet by vehicle market segment. The purpose of by-segment analysis is to understand the technology adoption situation and fuel economy levels of typical car classes in the Chinese market, in order to investigate any technological gaps among major market segments. Given the similarity between the Chinese and European passenger car segments, we conducted a by-segment comparison between the two regions, focusing on vehicle characteristics and efficiency technology application levels.

4.1 Description of car classification methodologies

Two Chinese national standards introduced in 2001 provided distinct methodologies to classify passenger cars depending on various regulatory or non-regulatory purposes. GB/T 15089-2001 divides four-wheeled passenger vehicles into M1, M2, and M3 categories (similar to the European system) according to gross vehicle weight and seating capacity. This classification is used mostly for regulatory purposes, including vehicle certification and all kinds of technology standards, as well as fuel consumption standards. Passenger cars under the fuel consumption regulation are defined as M1 or M1G category, with vehicle weight under 3.5 tons. From there, the China Association of Automobile Manufacturers (CAAM) further divides the fleet into four subdivisions – basic cars (or sedans), SUVs, multi-purpose vehicles (MPVs) and cross-style passenger cars – depending on the vehicles' use.[11] Among these subdivisions, cross-style vehicles are a unique category in China. Different from crossover vehicles in other parts of the world, cross-style vehicles are essentially car-derived minivans that are used mainly in rural areas to carry passengers or goods.

The other national standard, GB/T 3730.1-2001, divides four-wheeled motor vehicles into passenger cars, commercial vehicles, and trailers based on usage purposes. Passenger cars are further divided into 11 types (such as saloon, convertible, hatchback, coupe, wagon etc.) according to body type and door/window structure. This classification is more conceptual and mainly serves nonregulatory purposes, such as car issuance, registration and license and other statistics.

However, the above vehicle classifications both deviate somewhat from the market divisions that are most relevant to manufacturing design platforms and consumers' utility interest; therefore, they do not fit well in the context of this study. Since the focus of this study is vehicle technology adoption and development, vehicle classification must reflect basic structural and engineering design distinctions. In the pro-

11 In the CAAM classification, the definitions of basic cars, SUVs, and MPVs are straightforward and similar to that in other parts of the world. The definition of cross-style cars, on the other hand, is vague. CAAM suggests that cross-style vehicles are passenger cars that do not fall into the above three categories. They mainly refer to car-derived minivans (微型面包车 in Chinese). Typical cross-style vehicles in China are the Chana Star and Wuling Zhiguang. Source: China Association of Automobile Manufacturers, "Explanation to the Vehicle Classification," retrieved from http://www.auto-stats.org.cn/ReadArticle.asp?NewsID=3134.

duction practice, a car manufacturer usually builds a relatively small number of vehicle platforms that share a set of common design, engineering features, and even major components over a large number of outwardly distinct models. Efficiency technologies or technology packages applied to these different platforms may vary, and so do the energy-saving results. On the other hand, vehicle classification should be closely linked to consumer utility.

The most commonly used light-duty vehicle segmentation methods – adopted by manufacturers, vendors, companies conducting vehicle market research and statistics, and major automobile product web portals such as Sina.com and Sohu.com's auto channels – are historically based on Volkswagen's (VW) original light-duty vehicle platform groups, i.e. from A00 class to D class. However, they may not adopt the exact same class coding as VW developed. The VW classification basically reflects major vehicle design platform differences and consumer utility choices. But unlike the European classification methodology, which focuses on vehicle physical features such as length, size, and engine size as the major segmentation clue,[12] vehicle price can be an important criterion to define car segment in China.

In this study, we adopt the following the data provider's segmentation method (Table 4.1), which in general is similar to the European style vehicle classification mentioned above but also incorporates vehicle price as a major criterion for segmentation of major car classes (mini to large).[13]

12 For example, the UK's Motor Vehicle Registration Information System uses engine displacement and vehicle length instead of price as the primary criteria for segmentation. Source: The Society of Motor Manufacturers and Traders (SMMT), UK New Car Registration by CO_2 Performance, 2005, p57. Retrieved from owcvp.org.uk/assets/reports/CO2%20Report%202005.pdf

13 As with any other vehicle classification system, this method is not perfectly accurate and comprehensive. The boundary between segments can be blurred, and a vehicle may fit into multiple categories or not completely satisfy the requirements for any. And as a vehicle can grow or shrink in size and displacement to meet the market demand over its successive generations, its segment assignment may differ significantly from its original versions.

Table 4.1

Passenger car segments in this study[14]

Segment	Description
Mini	Hatchback, up to 3.75 meters long, priced mainly around the RMB 40,000 mark, with some outliers up to RMB 60,000
Small	Hatchbacks up to 4.1 meters long, sedans up to 4.3 meters long, priced mainly around the RMB 40,000 mark, with some outliers up to RMB 60,000
Lower medium	Hatchbacks between 4.1 meters and 4.5 meters long, sedans between 4.3 and 4.6 meters, priced between RMB 80,000 and RMB 130,000
Medium	Usually a sedan, between 4.6 and 4.99 meters long, price between RMB 100,000 and RMB 180,000
Upper medium	Premium compact cars, around 4.5 meters long, priced from RMB 270,000
Large	usually a sedan with length of 5.0 meters or more, price greater than RMB 220,000, but more likely RMB 300,000+
Medium MPV	MPV with engine up to 2.0 liters, seating capacity 5 to 7 people
Large MPV	MPV with engine above 2.0 liters, seating capacity 7 to 8 people
AUV/MUV	Asian utility vehicle (AUV)/multi-utility vehicle (MUV): basic MPV, usually based on a pickup chassis, seating capacity 7–10
Entry sports	Usually a two-door coupe or convertible, engine up to 2 liters
Monocoque SUV	Compact SUV, seating for 5 people, engine usually around 2.0 liters
Medium SUV	SUV often with separate chassis, engines 2.2 liters and upwards, often 7 seats
Car van	Car-derived van: Front half passenger car, rear half boxy van
Minivan	Small bus based on Japanese Kei-car platform, engine around 1.0 liter
Van	Box-type vehicle designed to transport goods or people on a commercial basis

14 As mentioned previously, other sources, including some commercial automobile product websites, adopt different names for the categories though each segment refers to similar car models. For example, the lower medium segment in this classification methodology roughly equals the "compact car" category on Sohu.com's auto channel.

Since price is a major factor in classification, the boundaries between car classes (especially for smaller vehicle classes) sometimes can be fuzzy given the smaller difference of their prices. And vehicles close to the boundary between two classes may be categorized mainly according to the price. For example, Geely's high-selling King Kong model sedan is closer to a lower medium car in terms of length even though it is categorized as a small car for its cheaper price under this segmentation method. Table 4.2 lists vehicle size and engine size between the King Kong and typical lower medium car models (Volkswagen's Golf and Jetta), which shows that the King Kong is similar to a lower medium car except for its low price (under 60,000 RMB).

Table 4.2

Vehicle size and other features of King Kong, Jetta and Golf*

	King Kong 1.5–1.8L	Jetta 1.6L	Golf 1.4–1.6L
Vehicle length (mm)	4342	4415	4200
Footprint (sq m)	3.6	3.5	3.9
Displacement (cc)	1518	1595	1503
Price (RMB)	54,974	88,800	142,377

* Each model offers several variants of different engine sizes. Vehicle length, size, displacement and price data listed in the table are sales-weighted average numbers.

For simplicity and representativeness, this study focuses on seven major light-duty passenger vehicle segments – mini, small, lower medium, medium, large, SUV (both monocoque, or compact, and medium) and minivan – that account for about 94% of China's total 2010 passenger car sales (Figure 4.3).

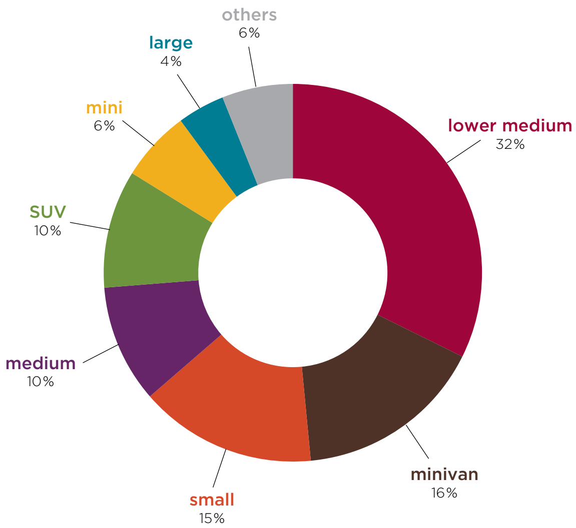


Figure 4.3

Major Chinese market segments included in the analysis, 2010

According to the above definitions, most major car segments in China are similar to their European counterparts except for the minivan, which in China and a few other Asian countries describes a unique size of car similar to the minicar but taller. Minivans in our raw database are actually included in the passenger car fleet as the cross-style subdivision according to the GB/T 15089-2001 classification. They have seating capacity of up to nine and the rear rows of the seats can be flipped or removed for greater inner volume. Because the earlier generations of minivans had a flat front design and the vehicles looked more cubical, they are often called "mini bread cars (微型面包车)." Minivans in the Chinese market mainly originated from Japan's mini utility vans (still popular in Japan and other Asian countries), such as the Toyota Hiace. Since their introduction to China in the 1980s, they have rapidly become popular in suburban and rural areas for their flexible usage and low prices. One common use was for farmers to transport agricultural produce to city markets.

4.2 Profile of major vehicle specifications by market segment

This subsection analyzes three basic vehicle physical and engine characteristics (engine displacement; engine specific power, defined as power/engine displacement ratio; and curb weight and footprint, defined as the area between the four wheels); three vehicle utility performance indicators (engine horsepower, designed maximum speed, and power-to-weight ratio), and fuel consumption for each of the seven major vehicle market segments. Additionally, based on an EPA study (US EPA, 2012), engine specific power could be indicative of engine technology adoption level – a higher value usually corresponds to a greater adoption of engine technologies, such as multiple valves, turbo/supercharger, variable valve timing, etc.

Table 4.4 provides a snapshot of the maximum and minimum values as well as sales-weighted averages for each parameter. Table 4.5 provides a comparison of the key vehicle characteristics of car models between the Chinese and European car market by segment. Figure 4.6 shows the market breakdown between Chinese independent automakers and JV automakers.[15] Figures 4.7 and 4.8 profile the sales distribution of these features and compares various vehicle segments side by side.

15 According to the Law of the People's Republic of China On Chinese-Foreign Equity Joint Ventures (2001 amendment), a joint venture auto manufacturer in China refers to a limited liability auto company jointly invested and operated by one or more Chinese independent auto manufacturers and one or more foreign auto manufacturers, with foreign investment no less than 25% of total registered capital, within China's territory. Source: http://www.gov.cn/banshi/2005-08/31/content_69775.htm (in Chinese); http://www.fairylaw.com/Article/zysd/200802/20080226130759.html (in English). For example, FAW-Volkswagen Automobile Co. Ltd. is a large-scale joint venture passenger car manufacturer between FAW Group Corporation and Volkswagen AG, with shares of 60% and 40%, respectively (source: http://www.faw.com/international/volkswagen.jsp).

		Mini	Small	Lower medium	Medium	Large	SUV	Minivan
Market share (%)		6%	15%	32%	10%	4%	10%	16%
Price (USD)	Avg	6789	11573	17199	28977	51061	28285	5401
Engine size (L)	Min	0.8	1	1.3	1.4	1.6	1.3	0.9
	Max	1.5	2	2	3.5	4.3	4.7	1.6
	Avg	**1.1**	**1.4**	**1.6**	**2**	**2.4**	**2.1**	**1.1**
Curb weight (kg)	Min	640	870	1090	1180	1520	1100	895
	Max	1076	1560	1480	1730	1930	2665	1325
	Ave	**918**	**1080**	**1258**	**1464**	**1684**	**1567**	**998**
Footprint (sqm)	Min	2.6	3.1	3.5	4	4.3	3.2	2.1
	Max	3.5	4.1	4.2	4.5	5	4.7	4
	Avg	**3.1**	**3.6**	**3.9**	**4.2**	**4.6**	**4.0**	**3.0**
Horsepower (kW)	Min	27	50	65	85	108	66	28
	Max	73	105	147	206	229	206	78
	Avg	**50**	**71**	**84**	**112**	**141**	**110**	**45**
Max speed (km/h)	Min	110	150	160	170	197	112	98
	Max	170	200	230	235	251	220	145
	Avg	**142**	**169**	**181**	**198**	**218**	**171**	**110**
Power/weight (W/kg)	Min	37	32	54	59	69	35	31
	Max	80	85	101	127	125	117	67
	Avg	**55**	**66**	**67**	**77**	**83**	**70**	**45**
Fuel consumption (L/100 km)	Min	5.1	5.1	6	6	6.8	6	4.9
	Max	7.9	8.3	9.4	10.7	11.8	14.7	8.8
	Avg	**6.4**	**6.7**	**7.4**	**8.5**	**9**	**9**	**7.6**

Table 4.4

Extreme values and sales-weighted averages for seven vehicle features by segment

EU 2010 data for EU-27

Segment	Mini-cars		Small		Lower medium		Medium		Upper medium		Off-road		Car-derived vans	
Market share	11%		29%		32%		11%		3%		9%		2%	
Representative model	Peugeot 107		Toyota Yaris		Volkswagen Golf		Toyota Avensis		BMW 5er series		BMW X3		Renault Kangoo	
Diesel share	7%		35%		59%		78%		81%		76%		77%	
	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel
Cylinder	3.6	3.8	3.9	3.9	4.0	4.0	4.3	4.1	5.2	5.0	4.2	4.4	4.0	4.0
Displacement [L]	1.1	1.2	1.3	1.4	1.5	1.7	2.0	2.0	2.7	2.5	1.9	2.2	1.5	1.6
Power [kW]	51	51	63	61	87	83	128	109	177	144	111	123	68	67
Auto. transmission share	12%	12%	9%	3%	14%	12%	36%	21%	74%	61%	24%	37%	4%	4%
Curb weight [kg]	904	975	1105	1173	1312	1405	1514	1565	1708	1764	1450	1772	1402	1428
CO_2 [g/km] (NEDC)	118	111	136	113	156	132	178	148	200	163	182	182	178	144

China 2010 passenger car data

Segment	Mini	Small	Lower medium	Medium	Large	SUV	Minivan
Market share	6%	15%	32%	10%	4%	10%	16%
Representative model	Chery QQ3	BYD F3	Hyundai Elantra	Honda Accord	Audi A6	Honda CR-V	Wuling Zhiguang
Diesel share	0%	0%	0%	0%	1%	6%	0%
Cylinder	3.5	3.9	4.0	4.1	5.0	4.1	4.0
Displacement [L]	1.1	1.4	1.6	2.0	2.4	2.1	1.1
Power [kW]	50	71	84	112	141	110	45
Auto. transmission share	17%	26%	44%	67%	89%	50%	0%
Curb weight [kg]	918	1080	1258	1464	1684	1567	998
CO_2 [g/km] (NEDC)	150	157	173	199	211	211	178

Note: Though a representative car model is given for each segment, the data are the sales-weighted averages for relevant parameters; unlike the EU segments that separate diesel and gasoline, the data values of China's segments are based on all available fuel types given that gasoline-powered vehicles make up more than 99% of the market.

Table 4.5

Illustration of representative models and comparison of key average vehicle features in China and EU by segment

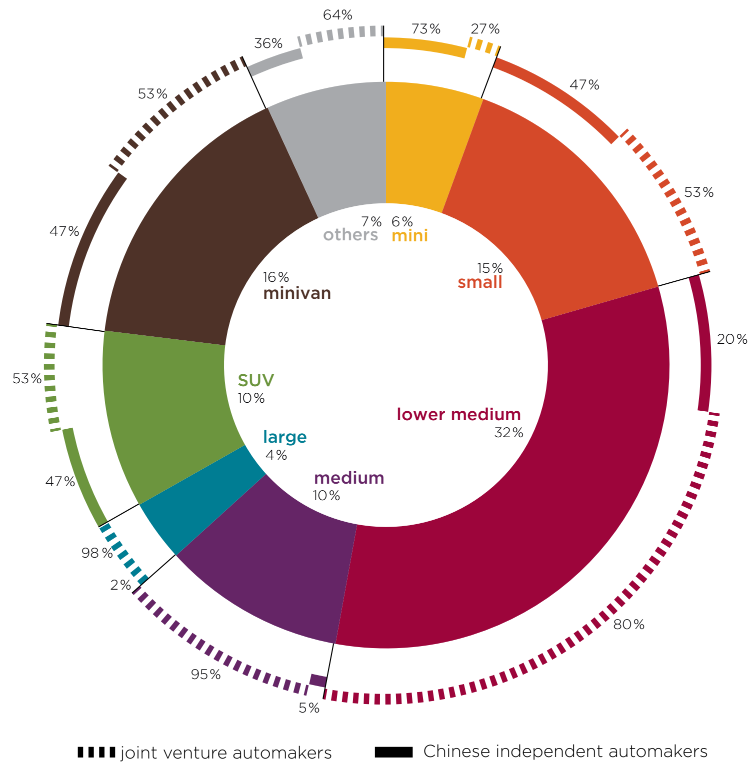


Figure 4.6

Market share of each segment for Chinese independent automakers and joint venture automakers

Combining the information above, we have the following observations for each market segment:

- With an average engine size of 1.1 L and average curb weight of about 920 kg, China's mini segment is similar to that of city cars in the European market. They represent 6% of the total car market according to 2010 sales. The segment is dominated by Chinese domestic brands, with nearly three-quarter of the sales from Chinese manufacturers. This is also the sub-market where the greatest price competition exists, and profit margin for automakers tends to be slim. The average price of a minicar in China is about $6,800, only slightly more than half of the price of a typical city car (Peugeot 107)[16] in Europe. Average fuel consumption of minicars is the lowest among all car segments in China, but the power-to-weight ratio of minicars is also the lowest. When compared to the EU, average fuel consumption of China's mini segment is 28% higher, as shown in Table 4.4.

- In comparison with minicars, small cars have much improved utility in terms of average engine size (27% increase) and engine power (42% increase) at 18% heavier weight. Fuel consumption increases by 5% over minicars. They are also similar to small cars in Europe, but they have 15% higher fuel consumption than the latter. With a series of market stimulus policies that favor small-engine vehicles (vehicles with engine displacement of 1.6 L or less) in recent years,[17] sales volume of small cars had grown rapidly[18] and took about 15% market share as the third largest segment in China's passenger car market, with roughly equal market share between Chinese independent and international brands.

16 Peugeot 107 specifications retrieved from http://www.carpages.co.uk/guide/peugeot/peugeot-107-guide.asp.

17 The energy-saving vehicle incentive program provides a one-time subsidy to consumers who buy cars with 1.6 L or smaller engines and meet certain fuel consumption limits. The vehicle program, led by China's National Development and Reform Commission, Ministry of Industry and Information Technology, and Ministry of Finance, was added to an overall energy-saving product program starting in June 2010. Source: http://www.jienenghuimin.org/.

18 Table 19-27, 2009–2010 vehicle production and sales by type (sales volume for passenger cars under 1.6 L engine). China Automotive Yearbook 2011.

- The lower medium segment is the largest segment in the Chinese passenger car market, representing 32% of total car sales in 2010. With average engine size of 1.6 L, average curb weight of 1,260 kg, average engine power of 84 kW, and average fuel consumption level 7.4 L/100 km, the lower medium segment is the closest to China's passenger car fleet average in all of the above key vehicle characteristics, and thus is a good representative of the typical passenger car in China. In the EU market, the lower medium is also the largest segment (Table 4.5)[19] and is the closest to the fleet average in model year 2010 (Table 5.1).

  The lower medium segment is similar between China and the EU, in terms of engine size, curb weight and power, but China's lower medium cars on average consume 12% more fuel per 100 km. From this segment and beyond, China's fleet shows significantly lower engine specific power than its EU counterpart – up to 14% lower in China's large car vs. the EU's upper medium segment. Starting with this segment, Chinese domestic brands begin to lose market share to foreign brands produced by JV automakers. Total sales of lower medium cars were about 4.3 million in 2010, only a little more than one-fifth of that from domestic automakers.

- Medium cars account for roughly 10% of China's 2010 car market. With average engine size of 2.0 L and average curb weight of 1,460 kg, the segment is comparable to medium cars in the European market except that it has 12% higher fuel consumption than its EU counterpart. The share of domestic brands decreases to less than 10% in the medium car segment.

- Large cars on average are the heaviest car segment in China's car market, and this segment has the highest engine power, top speed, power-to-weight ratio, and engine specific power. JV manufacturers produced 98% of 2010-model large cars. This segment is comparable to the EU's upper medium segment except for China's 5% higher fuel consumption. As in many other parts of the world, luxury and high-performance brands such as Audi and BMW are the most popular brands in this segment.

- Chinese SUVs on average are similar to off-road cars in the EU. The average footprint of a Chinese SUV is four sq m, or roughly between the typical size of a small and mid-sized SUV in the US; the average curb weight of Chinese SUVs is around 1,567 kg, less than that of a typical small SUV in the US market (1,640 kg).[20]

  Chinese SUVs cover a broad range of engine size, weight, power, performance, and fuel consumption levels, as shown in Figure 4.7, reflecting the variety of consumer demands as well as the differences in technology adoption in these vehicles. Although Chinese independent automakers produce a wide range of small to medium-sized SUV models at the lower fuel consumption rates – from the 1.5 L Chery Riich at 6L/100 km to the 2.5 L diesel Great Wall Haval at only 7L/100 km – the most popular models in the market are still from international brands, such as the Toyota Highlander, Land Cruiser, and Honda CRV, with fuel consumption rated from about 10–12 L/100 km. These models are heavier and powered by larger engines.

19 However, if considering only gasoline-powered cars, the EU small cars had the major market share (Table 4.5).

20 U.S. EPA 2008 light-duty vehicle database.

- The minivan segment is the second largest subdivision in China's car market, representing 16% of total car sales in 2010. The highest-selling model in the market is a minivan: the Wuling Zhiguang, with more than 600,000 units sold in 2010. In the EU market, as mentioned, there is nothing comparable to China's minivans. In this study, the car-derived vans in the EU were listed for reference, but they are found to be larger and heavier than China's minivans, even though average fuel consumption rates are similar.

  Minivans are in general the least efficient vehicles in the market – they have similar vehicle engine displacement, weight, and size to minicars, extremely low power output, and the worst performance in designed maximum speed and power-to-weight ratio among all segments. The fuel consumption of minivans was significantly higher than the former and only roughly comparable to that of lower medium cars. These vehicles are intended to be used in rural areas with relatively bad road conditions, and are not designed to perform well in high-speed mode. This partially explains their especially low designed maximum speed.

  Their low performance and poor fuel economy is also due to the less-ideal aerodynamic design – to achieve large inner space, the vehicles are designed to be taller than average cars. And as mentioned previously, the earlier generations of minivans mostly had flat fronts, which increased aerodynamic resistance. The outward body design of many of today's minivans has improved in that the front area of the vehicles has become more streamlined and bullet-shaped, though some still keep the original shape.

  More importantly, as evidenced in the next subsection, minivans lag behind in many fuel-saving technologies compared to the other segments – again to preserve their extremely low prices. The average (sales-weighted) price of a minivan was $5,400, 20% cheaper than a typical minicar and only roughly one-third of the average price of a typical car. This segment was roughly equally split by Chinese independent and foreign brands.

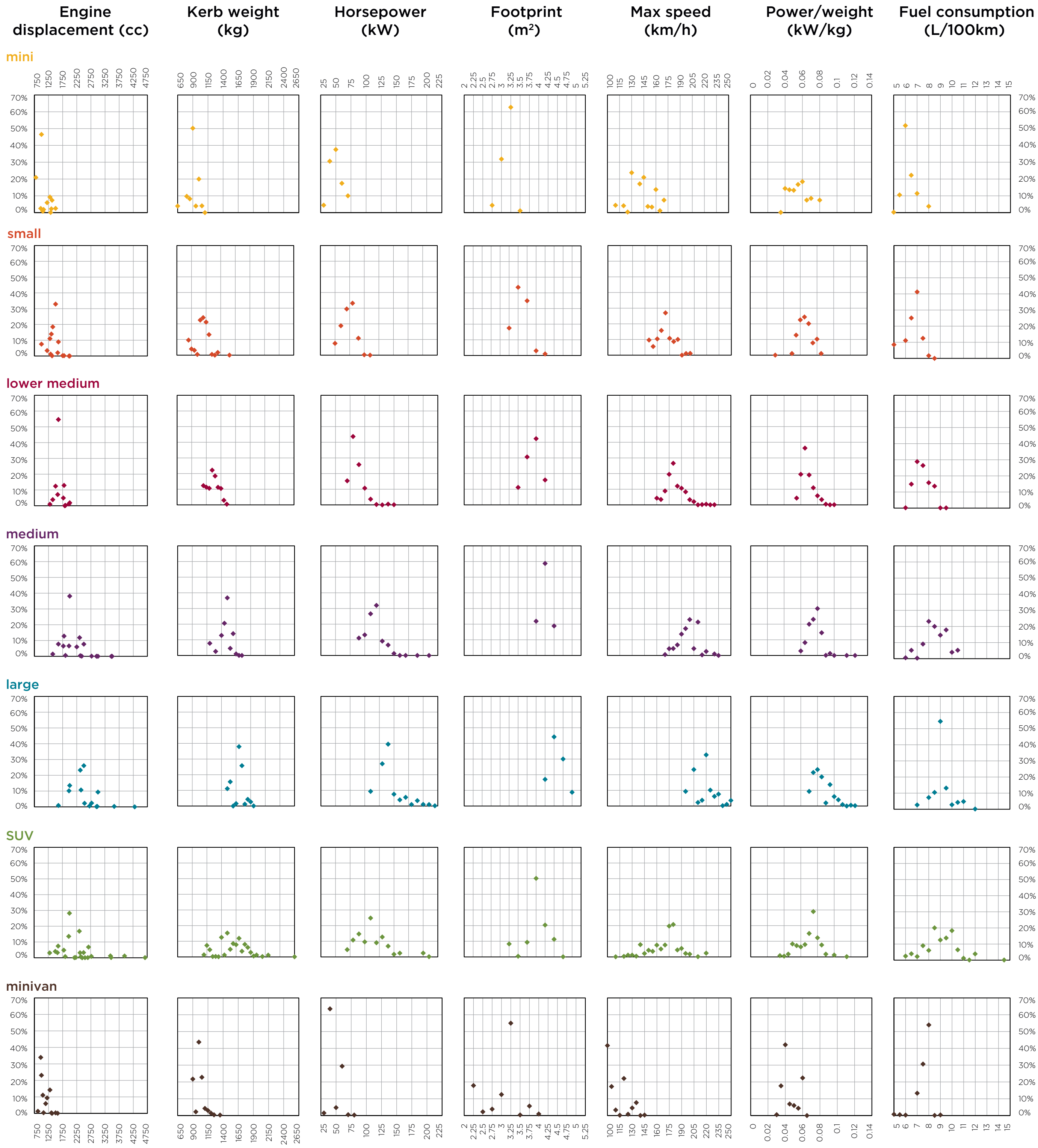


Figure 4.7

Distribution profile of engine displacement, curb weight, horse-power, footprint, designed maximum speed, power-to-weight ratio, and fuel consumption levels by vehicle segment

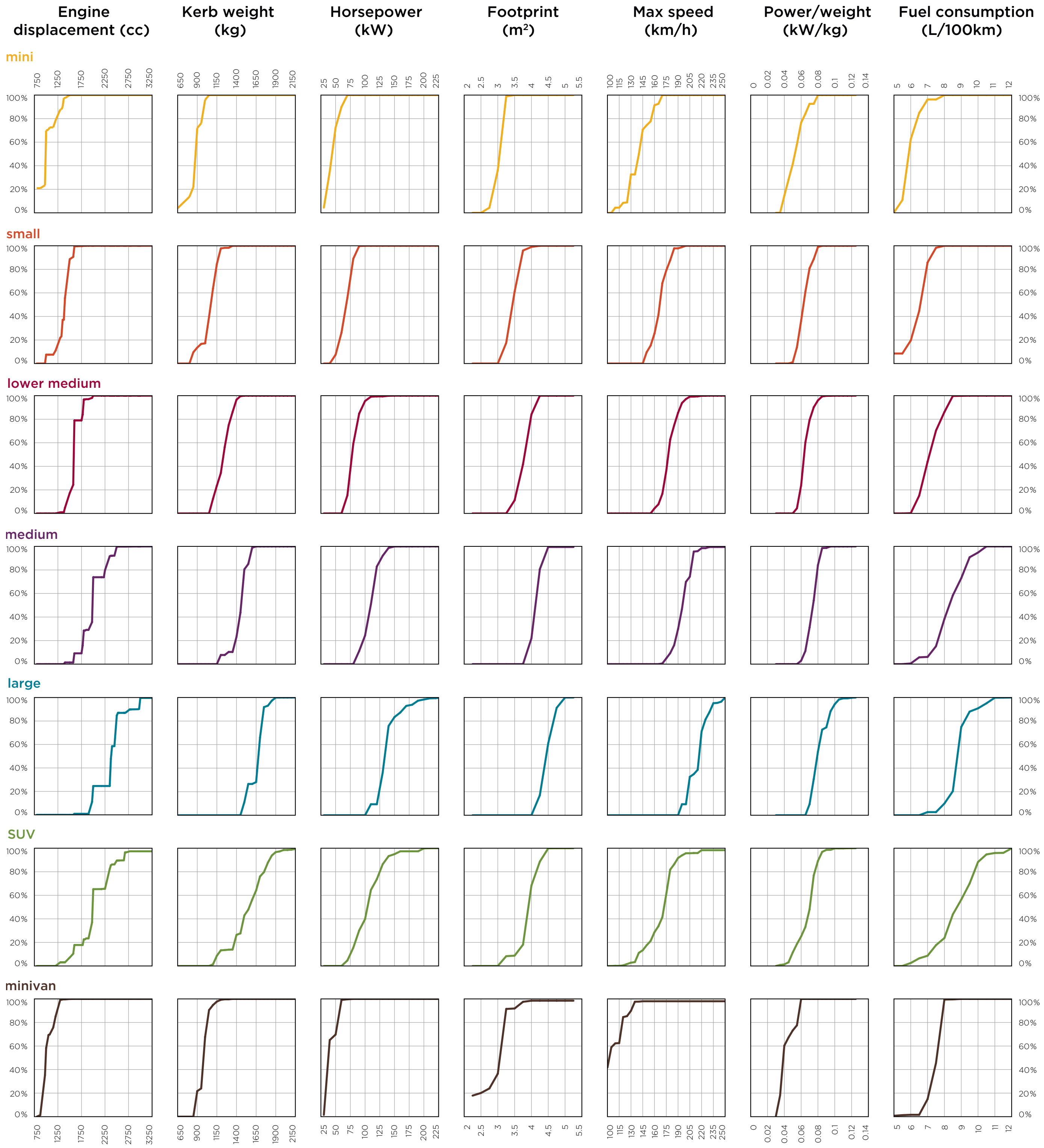


Figure 4.8

Cumulative distribution of engine displacement, curb weight, horsepower, footprint, designed maximum speed, power-to-weight ratio, and fuel consumption levels by vehicle segment

4.3 Fuel-efficiency technology adoption by segment

This subsection investigates the application of various engine and transmission technologies by market segments (Figure 4.9–4.11) and compares technology adoption rates between the Chinese and European fleets for each major car segment (Table 4.12). Most of China's passenger cars are powered by gasoline, while more than half of EU cars are powered by diesel. To compare both markets, only gasoline cars from the EU were considered except in the case of fuel type adoption rates in Table 4.12, which are based on the whole EU market.

4.3.1 Engine technologies

Gasoline is the primary fuel type for all car segments in China. Ninety-nine percent of the overall car fleet is powered by gasoline, while diesel, hybrid (conventional gasoline hybrid) and CNG vehicles each account for less than 1% of the new car sales in 2010.[21] Over the past decade, driven by oil-independence concerns, a few Chinese cities have promoted bi-fuel light-duty vehicles, including CNG and LPG/gasoline cars, mainly as the taxi fleet. However, few new bi-fuel car models have been developed in recent years. Therefore, our database only shows a couple of bi-fuel models, with tiny sales. Regarding the EU segments as shown in Table 4.5, diesel is the major fuel type for most segments except mini and small cars, while bi-fuel cars have started to emerge in most of the EU segments.

Diesel cars have been underdeveloped in China because of the country's supply and emissions concerns. Diesel is the primary fuel for heavy commercial vehicles, agricultural equipment, construction and manufacturing industries, and power generation. The fuel is traditionally subsidized by the central government to reduce costs for the agricultural sector. The distortion of the diesel market price has created a low incentive for refinery groups to supply diesel fuel. Because of that, diesel fuel shocks have been observed a few times in China in recent years,[22] which hindered the development of diesel cars.

From the air quality perspective, current diesel cars in China emit significantly higher NO_x and PM than their gasoline counterparts. Due to the lack of supply of low-sulfur diesel fuel in China, aftertreatment technologies such as diesel oxidation catalyst (DOC) and diesel particulate filter (DPF) cannot be effectively applied to diesel cars for reducing NO_x and PM emissions. There has been a debate for the past decade over whether to promote diesel cars. In 2007, the National Development and Reform Commission removed diesel engines from the list of "promoted automotive technologies" in its proposed Guiding Principles for Industrial Restructuring.[23] Some major cities, including Beijing and Guangzhou, have discouraged the mass application of diesel passenger cars for a long time. The main reason was that current diesel cars might contribute significantly to PM emissions in the already polluted urban air.[24] Recently, with the introduction of low- and ultra-low-sulfur diesel fuel standards in specific regions, there has been more discussion about reintroducing diesel cars into the market. The Beijing Environmental Protection Bureau announced the Beijing V diesel standard (equivalent to Euro V) and has conducted studies on the real-world emissions of compliant diesel cars fueled with the high-quality diesel fuel.[25] However, larger-scale development of diesel cars depends on the actual schedule of low-sulfur diesel fuel supply.

21 Data on electric vehicles, fuel cell vehicles, plug-in hybrid, and conventional hybrid vehicles are largely incomplete in our raw database, so these vehicles are either not included in our analysis or our analysis should not be considered thorough. At any rate, these vehicles do not yet have a significant market in China.

22 News reports about China's diesel shocks: http://news.xinhuanet.com/fortune/2010-11/10/c_12756018.htm.

23 Source: Sina Auto News, February 15, 2008, 汽车行业专家解读《产业结构调整指导目录》. Retrieved from http://auto.sina.com.cn/news/2008-02-15/0856347418.shtml.

24 "Beijing may reconsider diesel passenger cars": Interview with Du Shaozhong, Deputy Director of Beijing Environmental Protection Bureau, by Sina Auto on September 5, 2010. Retrieved from http://auto.sina.com.cn/news/2010-09-05/1025648780.shtml.

25 Source: http://www.bjepb.gov.cn/portal0/tab189/info8108.htm.

The large car and SUV segments were the only market subdivisions with diesel car sales – roughly 1% of large cars and 6% of the SUVs in the 2010 car market. There are two reasons behind the demand for diesel SUVs: a portion of the consumers had both higher torque demand (compared to other segments) and fuel-saving consideration. Although SUVs are relatively new in the Chinese market, modern efficient engine technologies such as common-rail injection and turbocharger have already been adopted widely in diesel SUVs. The top selling international brand of diesel SUV was the Santa Fe (by joint-venture manufacturer Hawtai–Hyundai). With its 2-liter engine equipped with both common-rail fuel injection and turbocharger, the fuel consumption was only in the range of 6 to 7L/100 km, comparable to a lower-medium gasoline car. The top-selling domestic brand was the Haval H series produced by Great Wall. Its 2.5–2.8L H3 and H5 models were equipped with turbochargers that allowed them to achieve fuel consumption of 7.5 to 8L/100 km, only slightly higher than an average gasoline car. Additional comparison between import and domestic SUVs is provided in Section 6.

Hybrid technologies have started to emerge in the medium car segment in China, as they have in the lower medium, upper medium and SUV segments in the EU. Limited by the data source, the raw database only includes one conventional hybrid model (the Toyota Camry hybrid) in the medium segment, and one plug-in hybrid model (the BYD F3DM) in the small segment. The 2.4L, four-cylinder hybrid Camry is similar to the current versions in the US market, with a similar fuel consumption rating (at 6L/100 km under the NEDC cycle). In China, however, its market price (the equivalent of about $50,700) was far above the reasonable price range for the comparable car in the US market. The F3DM is a plug-in hybrid version of BYD's top-selling F3 small car model. Similar to the regular F3, the F3DM has a one-liter engine and manual five-speed transmission. It is powered in part by a 6.5Ah nickel-metal hydride battery with 37 kW of electric output.

Regarding other technologies, it was found that larger segments from the lower medium to SUV had adopted more advanced technologies than those of smaller segments such as mini and small cars and minivans. Adopted technologies included gasoline direct injection, turbocharging, and variable valve timing (VVT). Almost half of large cars were equipped with six-cylinder engines; 33% employed gasoline direct injection (GDI) and 19% had turbochargers. However, all of the EU segments employed the turbo- or supercharger as shown in Table 4.12, and they had significantly higher adoption rates than their Chinese counterparts, especially from the lower medium to SUV segments. This might explain the comparably lower engine specific power of China's fleet in these segments, as discussed earlier. In turn, it may be a factor in the Chinese cars' higher fuel consumption than that of the EU across most segments. By comparison, the minivan segment was found not to employ VVT, variable valve lift (VVL), or turbocharging, and all its models had four-cylinder engines.

Figure 4.9

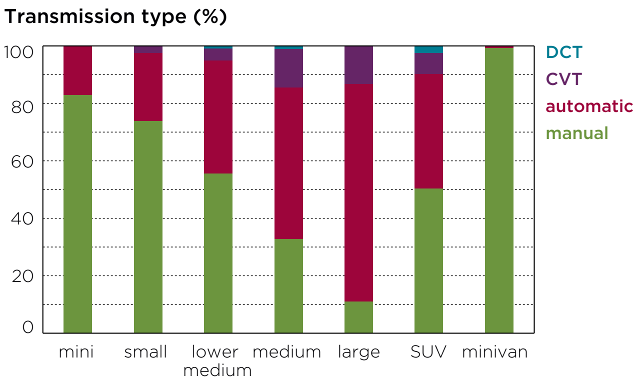
Engine technologies adoption by segment

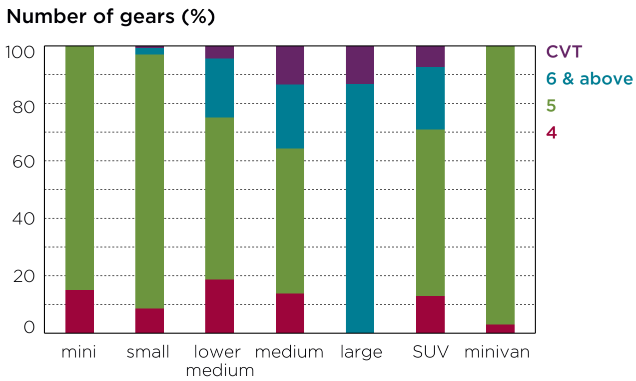
4.3.2 Transmission technologies

While the majority of the new car fleet in China had manual transmission with no more than five gears, the distribution of transmission type and number of gears varied to a great extent across different market segments. A clear trend was found of increased adoption of automatic transmission and continuous variable transmission from small to larger car segments. Dual clutch transmission only existed in 1–2% of the market share in a few segments (Figure 4.10). This is quite different from the US market, where automatic transmission dominates, and from the EU market, where manual transmission is the primary type for all segments except large cars. While less than 5% of mini and small cars had a six-speed or above gearbox, this ratio grew significantly to about one-fifth for lower medium and medium segments, then jumped to 87% for the large car segment. In comparison with their EU counterparts, except for large car and SUV segments, China's car segments demonstrated at least 29% lower adoption rates of higher-speed transmissions (six-speed or above), as shown in Table 4.12.

Figure 4.10

Transmission technologies adoption by segment





4.3.3 Drivetrain technologies

Figure 4.11 shows the drivetrain technologies for each segment. It is evident that more than one third of the SUVs are four-wheel drive (4WD), and most of smaller cars are front-wheel drive (FWD) while all minivans are rear-wheel drive (RWD).

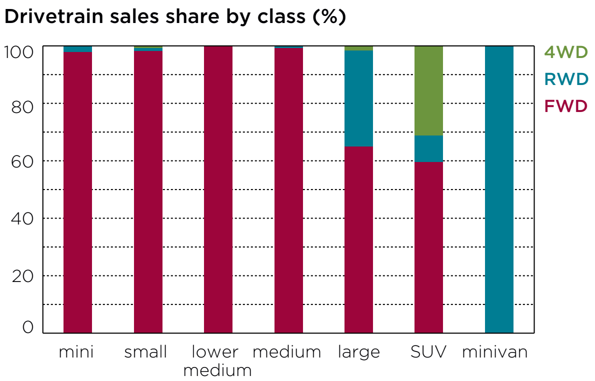


Figure 4.11

Drivetrain technologies adoption by segment

Parameters	Mini	EU Mini	Small	EU Small	Lower Medium	EU Lower Medium	Medium	EU Medium	Large	EU Upper Medium	SUV	EU Off-Road	Minivan	EU Car-Derived Van
Market														
Sales (million)	0.8	1.2	2	2.3	4.3	1.6	1.4	0.3	0.5	0.1	1.3	0.3	2.1	0.04
Share (%)	6%	21%	15%	38%	32%	27%	10%	5%	4%	1%	10%	5%	16%	1%
Price (USD)	6,789	12,046	11,573	15,681	17,199	22,341	28,977	36,280	51,061	53,162	28,285	28,197	5,401	17,850
Basic														
Engine size (L)	1.1	1.1	1.4	1.3	1.6	1.5	2.0	2.0	2.4	2.7	2.1	1.9	1.1	1.5
Curb weight (kg)	918	904	1080	1105	1258	1312	1464	1514	1684	1708	1567	1450	998	1402
Length (mm)	3631	3489	4126	3958	4502	4319	4796	4689	4955	4858	4481	4324	3737	4285
Width (mm)	1574	1617	1681	1700	1748	1785	1801	1817	1845	1845	1804	1797	1538	1791
Height (mm)	1503	1502	1482	1496	1466	1520	1472	1454	1484	1464	1713	1658	1888	1810
Footprint (sq m)	3.1	3.3	3.6	3.6	3.9	4.0	4.2	4.3	4.6	4.5	4.0	3.8	3.0	3.9
Utility														
Power (kW)	50	51	71	63	84	87	112	128	141	177	110	111	45	68
Torque (N.m)	91	-	128	-	154	-	199	-	253	-	208	-	85	-
Max speed (km/h)	142	158	169	158	181	190	198	219	218	238	171	183	110	161
Power-to-weight ratio (W/kg)	55	57	66	57	67	66	77	83	83	103	70	74	45	125
Engine specific power (kW/L)	47	46	51	48	52	56	56	63	59	69	53	59	41	46
Fuel Consumption and CO_2 Emissions														
Urban FC (L/100 km)	8.1	6.3	8.7	7.6	10	8.7	11.6	10.4	13.1	12.0	11.9	12.7	9.4	9.8
Extra-urban FC (L/100 km)	5.4	4.3	5.4	4.8	5.9	5.4	6.7	6.0	6.7	6.6	7.4	6.7	6.4	6.3
Combined FC (L/100 km)	6.4	5.0	6.7	5.8	7.4	6.6	8.5	7.6	9.0	8.6	9.0	8.9	7.6	7.6
Combined gCO_2/km	150	118	157	136	173	156	199	178	211	200	211	209	178	178

Technology Specifications

	Mini	EU Mini	Small	EU Small	Lower Medium	EU Lower Medium	Medium	EU Medium	Large	EU Upper Medium	SUV	EU Off-Road	Minivan	EU Car-Derived Van
Fuel Type														
Gasoline	100%	87%	100%	59%	100%	37%	99%	21%	99%	17%	94%	22%	100%	18%
Diesel	0%	7%	0%	35%	0%	59%	0%	78%	1%	81%	6%	76%	0%	77%
CNG/LPG/flexible fuel	0%	6%	0%	6%	0%	2%	0%	1%	0%	0%	0%	1%	0%	5%
Hybrid	0%	0%	0%	0%	0%	2%	1%	0%	0%	<1%	0%	1%	0%	0%
Transmission														
Manual	83%	86%	74%	89%	56%	83%	33%	61%	11%	25%	50%	71%	100%	96%
Automatic	17%	-	24%	-	39%	-	53%	-	76%	-	40%	-	0%	-
CVT	0%	1%	<1%	0%	4%	4%	13%	5%	13%	4%	7%	1%	0%	0%
DCT	0%	-	0%	-	1%	-	1%	-	0%	-	2%	-	0%	-
Automatic+CVT+DCT	17%	12%	26%	8%	44%	13%	67%	34%	89%	73%	50%	22%	0%	4%
Number of Gears														
4	15%	2%	9%	3%	19%	1%	14%	0%	0%	<1%	13%	1%	3%	0%
5	85%	60%	89%	64%	56%	43%	51%	19%	0%	28%	58%	22%	97%	40%
6 and above	0%	<1%	3%	10%	21%	29%	22%	50%	87%	51%	22%	13%	0%	0%
6	0%	<1%	3%	9%	19%	27%	21%	48%	76%	27%	19%	12%	0%	0%
7	0%	0%	0%	1%	1%	2%	1%	3%	2%	13%	2%	2%	0%	0%
8	0%	0%	0%	0%	0%	0%	0%	0%	9%	11%	0%	0%	0%	0%
Valve Configuration														
Dual overhead camshaft	65%		90%		78%		97%		100%		85%		16%	
Single overhead camshaft	35%		10%		22%		3%		0%		15%		84%	

Parameters	Mini	EU Mini	Small	EU Small	Lower Medium	EU Lower Medium	Medium	EU Medium	Large	EU Upper Medium	SUV	EU Off-Road	Minivan	EU Car-Derived Van
Number of Cylinders														
3	47%	39%	8%	13%	0%	0%	0%	<1%	0%	0%	0%	0%	0%	0%
4	53%	59%	92%	86%	100%	99%	93%	87%	48%	47%	95%	91%	100%	100%
5	0%	0%	0%	0%	0%	1%	0%	<1%	2%	1%	0%	1%	0%	0%
6	0%	0%	0%	0%	0%	<1%	7%	9%	50%	42%	5%	4%	0%	0%
8	0%	0%	0%	0%	0%	0%	0%	2%	<1%	7%	<1%	3%	0%	0%
Avg. No. of Cylinders														
	3.5	3.6	3.9	3.9	4.0	4.0	4.1	4.3	5.0	5.2	4.1	4.2	4.0	4.0
No. of Valves per Cylinder														
2	18%		0%		14%		3%		0%		1%		69%	
4	82%		100%		86%		90%		100%		99%		31%	
5	0%		0%		0%		7%		0%		0%		0%	
Fuel Supply														
Carburetor	0%		0%		0%		0%		0%		0%		2%	
Multipoint injection	96%		100%		96%		84%		67%		89%		26%	
Single-point injection	4%		0%		0%		0%		0%		0%		72%	
Common-rail (diesel)	0%		0%		0%		0%		0%		3%		0%	
Diesel injection	0%		0%		0%		0%		0%		0%		0%	
GDI	0%		0%		4%		16%		33%		8%		0%	
Fuel Intake														
Naturally aspirated	100%	97%	100%	88%	95%	67%	84%	47%	81%	41%	86%	70%	100%	92%
Turbo or supercharger	0%	2%	0%	8%	5%	27%	16%	50%	19%	57%	14%	23%	0%	2%
Valve Timing														
VVT	7%		13%		53%		89%		99%		63%		0%	
Inlet	7%		13%		50%		84%		58%		59%		0%	
Inlet and outlet	0%		0%		2%		4%		41%		4%		0%	
Valve Lift														
VVL	0%		8%		3%		14%		13%		13%		0%	
Continuous	0%		0%		0%		0%		11%		2%		0%	
Discrete	0%		8%		3%		14%		2%		11%		0%	
Drivetrain														
4WD and AWD	0%	1%	0%	0%	0%	1%	0%	10%	2%	10%	31%	48%	0%	0%
FWD	98%	93%	98%	98%	100%	91%	100%	58%	65%	11%	60%	47%	0%	98%
RWD	2%	5%	1%	0%	0%	3%	0%	30%	33%	78%	9%	2%	100%	0%

FC: fuel consumption
CVT: continuous variable transmission
DCT: dual clutch transmission
AT: automatic transmission
GDI: gasoline direct injection
VVL: variable valve lift
VVT: variable valve timing
4WD: four-wheel drive
AWD: all-wheel drive
FWD: front-wheel drive
RWD: rear-wheel drive

* For EU segments, data values other than fuel type are based on gasoline vehicles. For China's segments, data values are based on all fuel types given that gasoline vehicles dominate the market.

Table 4.12

Average features and technology adoption by segment

4.4 Summary

This section analyzes passenger car fleet characteristics and technology adoption status by major market segments. Except for minivans, most of China's segments were similar to their EU counterparts in terms of vehicle characteristics such as size, weight, and engine size. In terms of performance, most of the EU segments had greater values in power, max speed, power-to-weight ratio, and engine specific power than their China's counterparts.

Additionally, the average car in China was almost identical in size and weight to the average car in Europe. However, CO_2 emissions and fuel consumption of Chinese cars from most of segments were higher than those of their EU counterparts, which might be partially attributed to lags in adoption of technologies such as turbocharging, high gear transmission, etc.

The deployment of fuel efficiency technologies varied to a great extent by segment. More advanced technologies were used in larger cars than in smaller cars. This is partially due to the fact that small car segments were dominated by Chinese independent automakers, while mid-size and above classes were dominated by joint venture companies in which foreign automakers provided advanced technologies.

Minivans, despite their small size, had poor fuel efficiency comparable only to a typical mid-sized car. As manufacturers sought to keep their prices extremely low, very few minivans were equipped with advanced engine and transmission technologies.

5 COMPARISONS AMONG CAR FLEETS FROM DIFFERENT REGIONS

This section compares the fleet characteristics and technology adoption of light-duty passenger cars across world's three largest markets – the EU, US and China – as shown in Table 5.1 as well as Table 1.1.

Due to the differences in vehicle classification schemes adopted in various regions, the classification of light-duty passenger cars does not necessarily refer to the same set of vehicles in the three markets. In the EU and China, light-duty passenger vehicles, by definition, are M1-category vehicles with gross vehicle weight (GVW) less than 3.5 metric tons. As introduced in the previous chapter, these vehicles include basic cars (or sedans) and SUVs, and in China also include MPVs and certain car-based minivans.[26] In the US, light-duty vehicles (LDV) include passenger cars and light-duty trucks (SUVs, minivans, vans, and pickup trucks), and most small or two-wheel drive SUVs have been reconsidered as cars rather than light-duty trucks (US EPA, 2012). In this study, we separate light-duty passenger cars from the US LDV fleet for a fair comparison with European and Chinese light-duty passenger vehicles.

26 China Association of Automobile Manufacturers, "Explanation to the Vehicle Classification," retrieved from http://www.auto-stats.org.cn/ReadArticle.asp?NewsID=3134.

In the following comparison, the EU's gasoline-powered passenger cars are listed separately, because most of China and US passenger cars are powered by gasoline while more than half of EU passenger cars are powered by diesel. China's combined passenger car fleet in the table below includes both the domestic and import fleets. The next section will discuss in more detail the differences between the two.

Table 5.1 shows that China had a higher passenger car sales volume in 2010 than the EU or US. Average engine size, curb weight, and footprint of Chinese cars fell between that of EU gasoline-powered cars and US cars. Regarding performance, the Chinese fleet's values of most vehicle characteristics such as power, power-to-weight ratio, and combined fuel consumption on average are between the levels of the EU and US markets.

In terms of technology adoption, the available data for the EU and US are not as comprehensive as China's. The Chinese market share of cars with higher-gear transmissions (six-speed and above) is slightly higher than that of EU gasoline-powered cars, but is only about half that in the US car market. This might be because of the preference of manual transmission in the EU compared to automatic transmission in the US; in recent car models, automatic transmissions usually carry more gears than manuals.

China has the lowest adoption level of GDI among three markets; GDI market share in the EU was five times greater than that in China. Regarding turbocharging, China had a higher adoption rate than the US but lower than the EU.

Overall, the cycle-specific fuel economy rating (not corrected for test cycle differences) of the Chinese passenger car fleet is higher than the levels of the EU and US gasoline car fleets. When normalized to NEDC,[27] China's fleet-average fuel consumption falls between that of the other two markets. This gap in fuel economy performance could be attributed to technology use. Although adoption levels for some technologies fell in between those of the other two markets, the overall adoption rates of advanced technologies were lower in China.

27 See www.theicct.org/info/data/GlobalStdReview_Conversionfactor.xlsx for methodology of converting between test cycles.

Table 5.1

Fleet profiles and technology adoption by market

Parameters	EU PC Fleet[a]	EU Gasoline PC Fleet[a]	US LDV Fleet[b]	US PC Fleet[b]	China Combined PC Fleet
Sales (million)	13.31	5.89	11.11	7.15	13.76
Price (USD)	24,547	20,024	29,100	26341[c]	21,008
Basic Specification					
Engine size (L)	1.6	1.4	3.1	2.6	1.7
Curb weight (kg)	1,322	1,172	1,815	1,611	1,280
Footprint (sq m)	3.90	3.75	4.51	4.22	3.79
Utility					
Power (kW)	84	77	174[d]	156[d]	86
Max speed (km/h)	185	178	223	218	170
Power-to-weight ratio (W/kg)	62	63	96	97	65
Engine specific power (kW/L)	51	52	57	60	51
Acceleration time (s) 0–100 km/h	11.9	12.4	9.6	9.6	11.4
Fuel Consumption and CO_2 Emissions					
Urban FC (L/100 km)[f]	7.4	8.1	9.8	8.6	10.4
Extra-urban FC (L/100 km)[f]	4.9	5.1	6.4	5.6	6.3
Combined FC (L/100 km)[f]	5.8	6.2	8.3	7.3	7.8
Combined NEDC FC (L/100 km)	5.8	6.3	9.4	8.1	7.8
CO_2 (combined)[g]	143	145	195	171	183
Technology Adoption					
Fuel Type					
CNG/LPG/flexible-fuel	3%	0%	0%	0%	0%
Diesel	51%	0%	1%	1%	1%
Unleaded gasoline	44%	100%	96%	94%	99%
Hybrid: unleaded gasoline/electric	1%	0%	4%	5%	<1%
Transmission					
Automatic	9%	14%	84%	80%	34%
CVT	2%	1%	11%	14%	5%
DCT	3%	-	1%[e]	2%[e]	1%
Manual	86%	83%	4%	5%	60%
Number of Gears					
≤4	1%	2%	25%	29%	12%
5	59%	51%	24%	21%	66%
≥6	38%	17%	41%	36%	17%
Valve Configuration					
Dual overhead camshaft	-	-	68%	78%	74%
Single overhead camshaft	-	-	22%	18%	26%
Number of Cylinders					
3	7%	13%	0%	4%	4%
4	88%	83%	50%	91%	90%
5	1%	<1%	1%	0%	0%
6	4%	2%	35%	5%	6%
8	0%	1%	14%	0%	0%

Parameters	EU PC Fleet[a]	EU Gasoline PC Fleet[a]	US LDV Fleet[b]	US PC Fleet[b]	China Combined PC Fleet
Number of Valves per Cylinder					
2	-	-	15%	7%	17%
Multi-valve	-	-	85%	94%	83%
Fuel Supply					
Carburetor	-	-	0%	0%	<1%
Diesel injection	-	-	1%	1%	<1%
Gasoline direct injection	14%	32%	8%	8%	6%
Multipoint injection	-	-	77%	80%	82%
Single-point injection	-	-	0%	0%	11%
Sequential fuel injection	-	-	14%	11%	0%
Air Intake					
Turbocharged or supercharged	59%	16%	3%	4%	7%
Valve Timing					
VVT	-	-	84%	91%	44%
Valve Lift					
Continuous VVL	-	-	2%	2%	1%
Discrete VVL	-	-	15%	16%	5%
Drivetrain					
FWD	83%	88%	60%	83%	74%
RWD	7%	6%	14%	12%	21%
4WD	9%	4%	27%	5%	5%

Notes:

a Source: ICCT EU database and ICCT European Vehicle Market Statistics: 2011 Pocketbook (Campestrini, M., & Mock, P., 2011)

b Source: EPA 2010 database, EPA 2011 and 2010 Trends Reports

c Based on edmunds.com data center

d The US values are reported as net power, which is different from China's rated power. Based on GB 7258-2004, US values were converted to rated power

e Automatic without lockup from 2011 EPA trends report is assumed to be DCT

f Fuel consumption – region specific test cycle used; for US data, lab data rather than adjusted data used

g CO_2 data – region specific test cycle used; for US, raw FTP and HWY lab data rather than adjust values in 2011 EPA Trends report was used; for China, the whole fleet was assumed to be on gasoline for CO_2 calculation

FC: fuel consumption
CVT: continuous variable transmission
DCT: dual-clutch transmission
VVL: variable valve lift
VVT: variable valve timing
FWD: front-wheel drive
RWD: rear-wheel drive
4WD: four-wheel drive

6 TECHNOLOGY ADOPTION BY DOMESTIC VS. IMPORT FLEET

This section analyzes and compares the adoption status of fleet features and fuel efficiency technologies between Chinese import and domestic passenger cars.

6.1 Fleet characteristics comparison

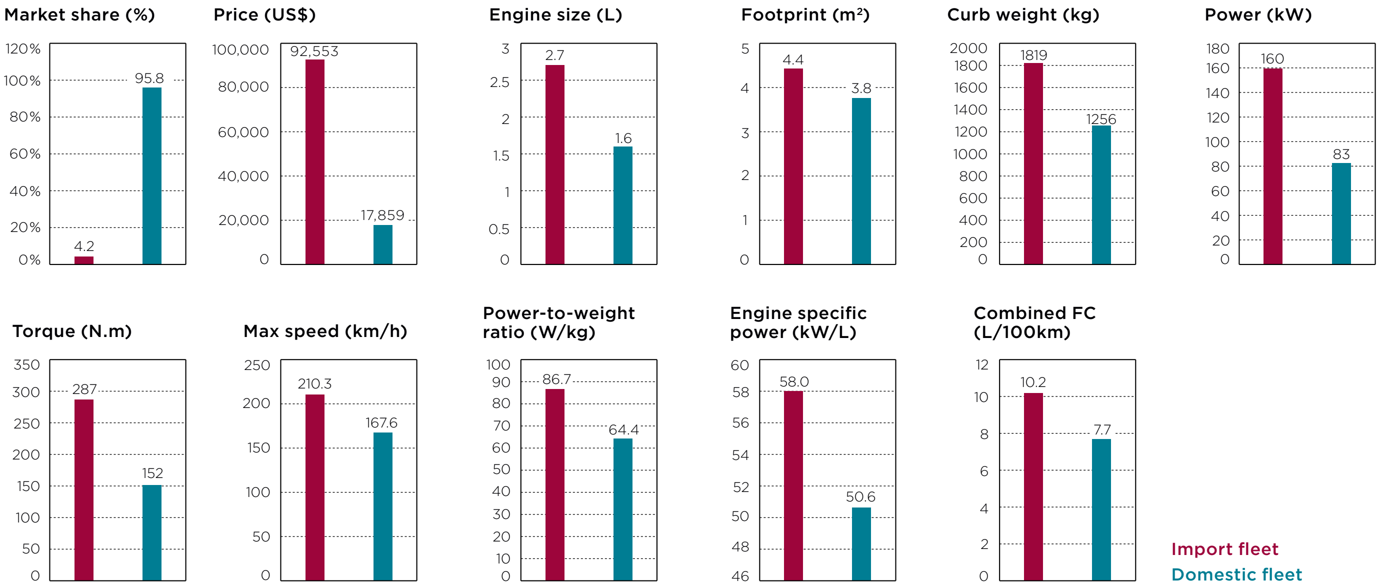
In this subsection, we computed sales-weighted average basic fleet characteristics, including engine size, curb weight, footprint, power, torque, max speed, power-to-weight ratio, engine specific power, and fuel consumption for both domestic and import fleets.

Figure 6.1 shows the average vehicle specifications for both fleets. It shows that the majority of sales (over 95%) were of domestic vehicles, while import vehicles made up less than 5%. Regarding the average sale price, the import vehicles were more than five times as expensive as domestic vehicles, which might be partially attributed to China's high tariffs.

Compared to the domestic fleet, the import fleet had more than 70% larger fleet-average engine size, 45% heavier curb weight, 93% more power, 25% higher max speed, 35% higher power-to-weight ratio, and 15% higher engine specific power. Import cars consumed 32% more fuel per 100 km.

Figure 6.1

Vehicle specifications of import and domestic fleets



6.2 Distribution of vehicle characteristics

In this subsection, sales distributions by different vehicle characteristics were analyzed and compared between the domestic and import fleets, as shown in Figure 6.2. The y-axis represents percent sales compared to the total sales volume and x-axis represents the parameters. The figures in the top two rows represent market share distributions, and the lower two rows represent cumulative distribution function.

Figure 6.2 shows domestic vehicles sold with engine size ranging from around 800 to 4,600 cc, and import vehicles with a wider range of 1,000 to 6,700 cc. The domestic and import fleets show the highest sales volume with engine size around 1,600 and 3,000 cc, respectively.

Regarding curb weight, compared to the domestic fleet the distribution curve of import fleet has a slight right shift, because a large portion of domestic vehicles range from 650 to 2,000 kg while import vehicles range from 1,000 to 2,700 kg. Figure 6.2 also shows that the import fleet had a much wider range of power; almost all (98%) of domestic vehicles' engine power is below 140 kW, while over half of import vehicles produced power above 140 kW.

The greater variation of combined FC was observed from import fleet. Similar to curb weight, fuel consumption distribution of the import fleet shifts to the right compared to the domestic fleet. More than one-third of domestic cars met 7 L/100 km, while only roughly 3% of import cars reached the same level.

Both fleets present the highest sales volume at max speed about 180 km/h, while 85% of import fleet and less than one third of domestic fleet could have higher top speed than the same value.

Regarding the power-to-weight ratio, it shows the ranges of 0.03 to 0.29 kW/kg for the import fleet and 0.03 to 0.13 kW/kg for the domestic fleet, respectively. The highest sales volume for import and domestic fleets occurred at about 0.08 and 0.06 kW/kg, respectively, indicating that the import fleet presented much better performance in terms of acceleration.

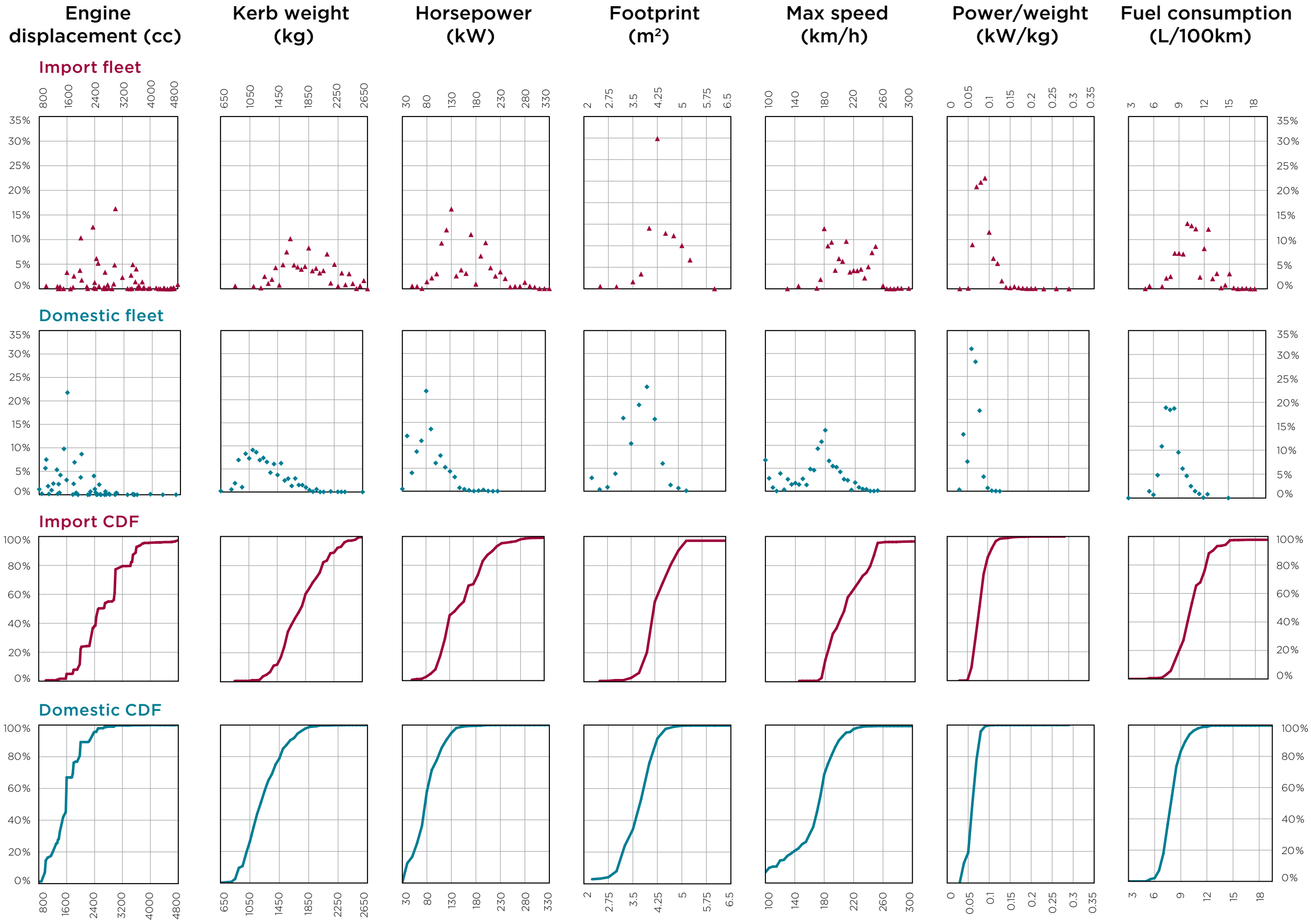


Figure 6.2

Sales distributions of import and domestic fleets

6.3 Correlation between fuel consumption and key vehicle technical parameters

Figure 6.3 shows the correlation of combined FC with other parameters such as curb weight, engine displacement, footprint, power, acceleration 0–100 km/h, torque, as well as the correlation of acceleration time with engine specific power and power-weight ratio. Each point represents one single data entry (one model) in the raw database, and do not represent sales-weighted averages like those in the previous discussion.

It is evident that poorer fuel economy is the tradeoff for better utility performance, higher torque, larger engine, and heavier vehicle weight. In general, heavier, bigger-engine vehicles with faster acceleration consumed more fuel.

In addition, Figure 6.3 shows a wider variation in terms of combined FC for the import fleet at a curb weight above 1,500 kg. Consequently, the overall fitting curve of import fleet shifts a little upwards above the curve of domestic fleet. Also noted is the heavier curb weight, the wider gap between two fitting curves. This might be attributed to the fact that some premium SUVs, luxury and sports cars were imported and they were equipped with significantly larger engines, such as the Cadillac Escalade premium SUV with a 6,162 cc engine, the Mercedes SL sports car with a 6,208 cc engine, the Bentley Continental GT with a 5,998 cc engine, and the Maserati Quattroporte luxury car with a 4,691 cc engine. These cars had very low sales volumes but did help shift the curves upwards. In addition, they reflect a wide variety of demand from the passenger car market.

Figure 6.3 shows that vehicles with higher engine specific power demonstrate faster acceleration. As mentioned previously, the high engine specific power usually indicates the adoption of more advanced engine technologies, such as multi-valve, VVT, and turbo/supercharging, as well as use of higher octane fuel (US EPA, 2012). Higher adoption level of these technologies could be connected to the better performance.

Strong correlation is observed between acceleration and power-to-weight ratio, which supports this study's use of power-to-weight ratio as a substitute for acceleration, given the limited data availability on the latter. In general, larger power-to-weight ratio corresponds to less time to accelerate from 0 to 100 km/h. The power-weight ratio variations of the domestic fleet are quite narrower, and all are below 130 W/kg. Wider variations of engine displacement and power were found for the import fleet, as shown in Figures 6.2 and 6.3. Further investigation found that the percentage of import vehicles at power-weight ratios equal to or greater than 130 W/kg accounted for only about 2% of the fleet. Most of those cars were luxury cars, sports cars, or SUVs, and over half of them had very fast acceleration speed and they only needed five or fewer seconds to reach the speed of 100 km/h.

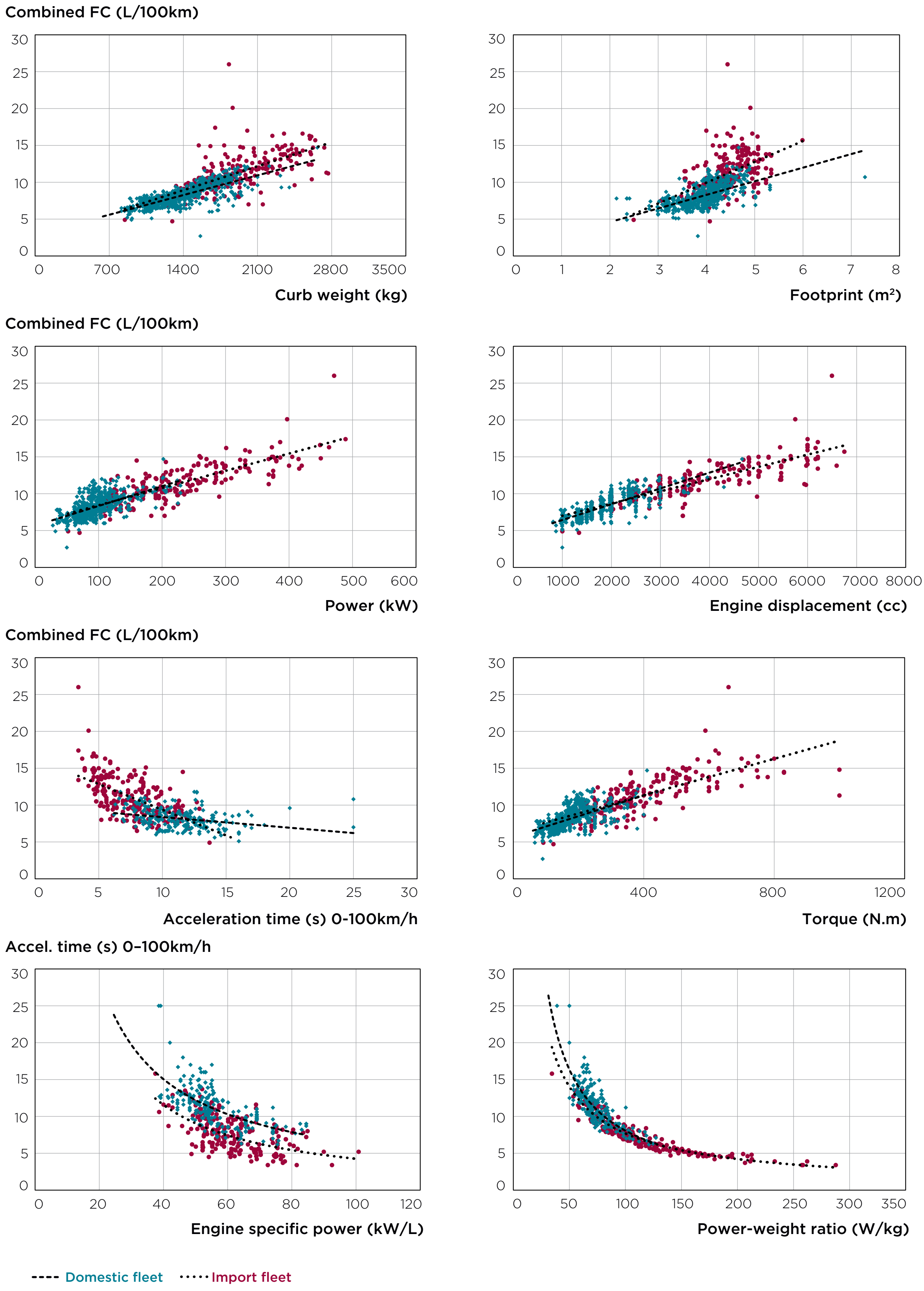


Figure 6.3

Correlation of combined FC and acceleration time with other parameters

6.4 Import vs. domestic SUV

Among import passenger cars, SUVs had major share, as shown in Figure 6.4. They were about 47.7% of the total import fleet, followed by 10.4% for luxury cars. Figure 6.5 compares import and domestic SUVs in terms of engine size, curb weight, power, max speed, combined fuel consumption, footprint, power-to-weight ratio, and engine specific power. Compared to domestic SUVs, their import counterparts, on average, had 33% larger engine size, were 22% heavier, had 45% higher power, increased 16%in max speed, increased 17% in power-to-weight ratio and 5% in engine specific power, and had 9% larger footprints. As a tradeoff, import SUVs consumed 18% more fuel (10.5 L/100 km vs. 8.9 L/100 km). All of import SUVs and about 94% of domestic SUVs met the Euro 4 standard.

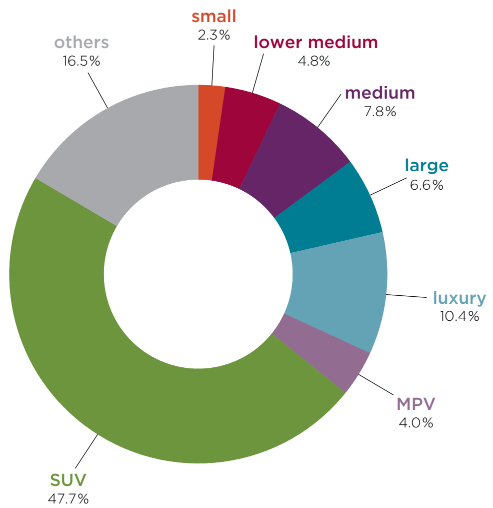


Figure 6.4

Market share by vehicle segment of import fleet

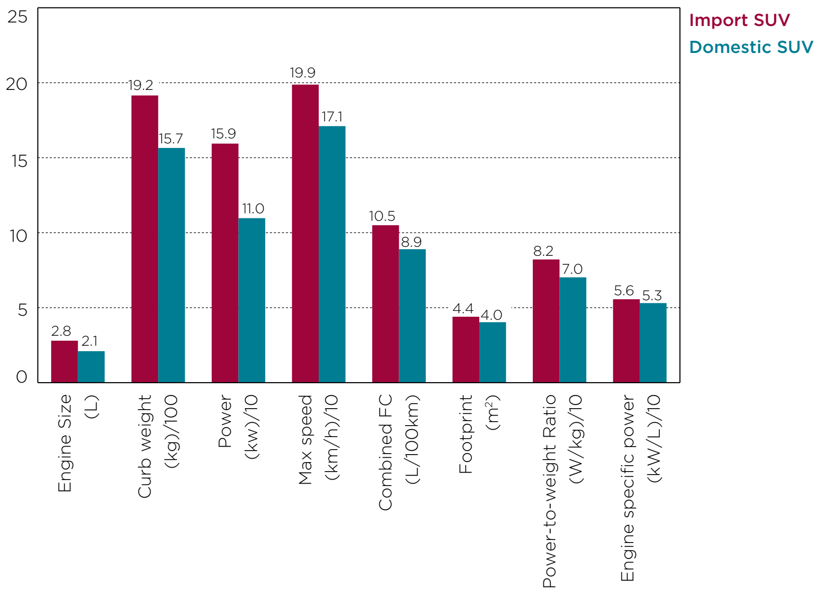


Figure 6.5

Comparison between import and domestic SUVs

6.5 Technology adoption of import and domestic fleets

This subsection provides the details of technology adoption in the import and domestic fleets.

6.5.1 Engine technologies

Figure 6.6 compares a variety of engine technologies adopted by the two fleets. Both fleets had most of their vehicles on gasoline, but each fleet had 1% on diesel fuel. Our limited data on hybrid vehicles show that gasoline hybrids account for 3% of the import fleet and less than 0.1% of the domestic fleet. Our market-share data for domestic hybrid vehicles is in general consistent with major vehicle market statistical sources such as the China Association of Automobile Manufacturers[28] and China Automotive Technology and Research Center.[29] However, our limited database only shows two hybrid models with significant (over 400) sales volume, compared to a total of 31 new hybrid passenger car models certified and announced by the MIIT that year.[30]

Multi-valve technology has become relatively mature compared to other technologies, as it was employed by more than 80% of the domestic fleet and 95% of the import fleet, respectively. Most of the domestic fleet (93%) was still using naturally aspirated engines without advanced air intake technologies, such as turbochargers or superchargers. When the engine is downsized with an added turbocharger, the fuel efficiency could be significantly improved without compromising the vehicle's performance. In comparison to the domestic fleet, the import fleet shows almost three times higher adoption of advanced air intake technologies, which partially explains that on average the import fleet delivers 15% higher engine specific power.

Both fleets widely adopted the double overhead camshaft (DOHC), indicating its maturity in the market. As mentioned, the average engine displacement of the domestic fleet was significantly smaller than that of the import fleet, as shown in Figure 6.6 – four- and six-cylinder engines were almost equally used in the import fleet, while most of the domestic fleet was equipped with four-cylinder engines.

Regarding fuel injection technologies, the most used technology in both fleets was multipoint injection. The use of gasoline direction injection (GDI) was about four times higher in the import fleet than in the domestic fleet. In the domestic fleet, single-point injection was still in use (about 12%), and it was almost exclusively on minivans, which might contribute to their poor fuel economy.

In terms of variable valve timing and lift technology, more than 90% of the import fleet employed VVT, and inlet-only and inlet-and-outlet continuous variable CVVT were almost equally adopted. The domestic fleet adopted inlet-only CVVT, but over half of the fleet was not equipped with VVT technologies. VVL was adopted by 23% of the import fleet, a rate about three times higher than the domestic fleet. In the import fleet, this technology was applied primarily to premium models such as BMWs and Porsches.

28 Ministry of Industry and Information Technology, "2010 Annual Report Automotive Industry (2010年汽车工业经济运行报告)." Retrieved from http://www.miit.gov.cn/n11293472/n11293832/n11294132/n12858417/n12858612/13572237.html.

29 Energy Saving and New Energy Vehicle Yearbook, 2010, China Automotive Technology and Research Center, p244.

30 Ministry of Industry and Information Technology, China Automobile Fuel Consumption Website. The number of hybrid passenger car models was obtained by counting models announced in 2010. Retrieved from http://chinaafc.miit.gov.cn/.

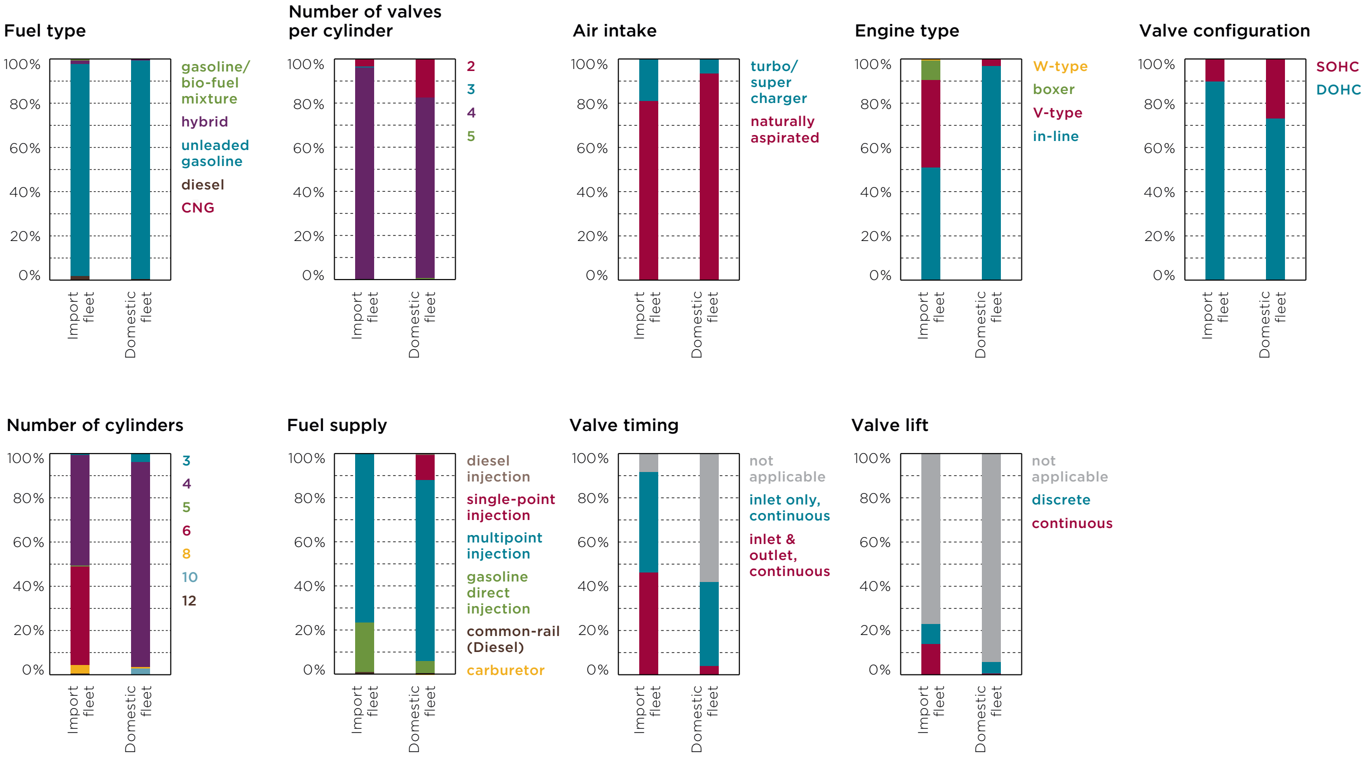


Figure 6.6

Engine technologies adoption by import and domestic fleets

6.5.2 Transmission technologies

Figure 6.7 shows adoption of transmission technologies. Most import vehicles employed automatic transmission, while most domestic vehicles were equipped with manual transmission. The import fleet had over twice the adoption rate of dual clutch than the domestic fleet. The average number of gears in a domestic car was five, while the average in an import car was six. This might be attributed to the fact that the import fleet was primarily automatics while the domestic fleet was primarily manuals, as automatics usually have a higher number of gears than manuals.

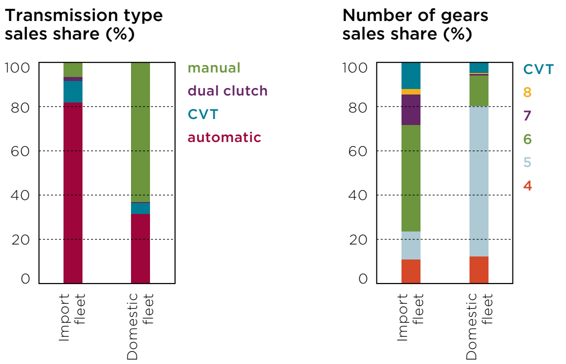


Figure 6.7

Transmission technologies adoption by import and domestic fleets

6.6 Summary

In summary, compared with domestic vehicles, on average import vehicles were 70% larger in engine size, 45% heavier, and almost double in power with 25% higher max speed and 35% higher power-to-weight ratio. But fuel consumption of import vehicles, on average, was 32% higher than that of the domestic fleet. While a greater share of advanced engine and transmission technologies was found in import vehicles than in domestic cars, the efficiency gain from these technologies was used not to improve fuel economy, but to boost various vehicle utility features such as higher top speed, greater power output, and power-to-weight ratio.

7 FLEET CHARACTERISTICS AND TECHNOLOGY ADOPTION BY MAJOR DOMESTIC MANUFACTURERS

This section analyzes fleet characteristics, technology adoption, and fuel consumption levels among major domestic manufacturers with the highest sales volume in 2010. We have included 18 manufacturers, including joint ventures (JVs) and Chinese independent automakers, which represent more than 80% of the passenger car market. Among them, Chang'an had the largest market share of 8.3%, closely followed by Shanghai–GM, SAIC–GM–Wuling, and Shanghai–VW. Most of these top 18 manufacturers were JV manufacturers, except six Chinese independent automakers: Chang'an, Chery, BYD, Geely, Great Wall, and Tianjin-FAW-Xiali. Among 11 Chinese automotive groups (An et al., 2011), 10 of them, all except Brilliance Auto, have manufacturers that are included in Table 7.1.

These analyses serve two main purposes. First, we profiled each major Chinese automaker's fleet features and its status of efficiency technology adoption. Second, we offer insight into whether there were significant differences between Chinese independent automakers and JV automakers in terms of technology adoption levels.

Table 7.1

Sales share by major domestic manufacturers

Auto manufacturers	Sales (million)	Share
Chang'an	**1.1**	**8.3%**
Shanghai-GM	1.09	8.3%
SAIC-GM-Wuling	1.06	8.0%
Shanghai-VW	1	7.6%
Bejing-Hyndai	0.7	5.3%
Dongfeng-Nissan	0.69	5.3%
FAW-VW	0.69	5.3%
Chery	**0.55**	**4.2%**
Guangqi-Honda	0.53	4.0%
BYD	**0.47**	**3.6%**
Chang'an-Ford	0.39	3.0%
Tianjin-FAW-Toyota	0.39	2.9%
Geely	**0.38**	**2.9%**
Dongfeng-Citroën-Peugeot	0.37	2.8%
Dongfeng-Yueda-Kia	0.33	2.5%
Great Wall	**0.29**	**2.2%**
FAW Car	0.27	2.1%
Tianjin-FAW-Xiali	**0.25**	**1.9%**

Bold cells: Chinese independent brands
Other cells: joint venture manufacturers

7.1 Major vehicle specifications and fuel consumption by manufacturer

This subsection compares sales weighted average fleet profile of each top manufacturer in terms of engine size, curb weight, power, torque, max speed, power-to-weight ratio, combined FC, price, and vehicle sizes, as shown in Figures 7.2 to 7.11, respectively. For each figure, manufactures are arranged from left to right, representing the sales volume from the larger to smaller. The dashed lines represent the average values across the domestic fleet. To distinguish between Chinese independent automakers and joint venture manufacturers, we use two different shades in the figures. Dark blue columns represent the independents, while light blue columns represent the joint ventures.

7.1.1 Engine size

Figure 7.2 compares engine sizes, showing that most JV manufacturers had engine size equal to or above the fleet average, except SAIC-GM-Wuling. However, five of six Chinese independent automakers had engine sizes below the average. Guangqi-Honda had the largest average engine size at 2.0 L, followed by FAW-Car at 1.9 L. SAIC-GM-Wuling had the smallest value among the top 18, at 1.0 L, followed by Tianjin-FAW-Xiali and Chang'an, both at 1.2 L.

One of the main reasons that Guangqi-Honda had the largest engine size on average might be because popular cars such as the Honda Accord and Honda CRV were sold in great numbers and their engine sizes are above 1.9 L. Regarding the manufacturers with smaller engine displacement, such as SAIC-GM-Wuling, minivans with engine size of 1.2 L or below dominated their market.

7.1.2 Curb weight

Figure 7.3 shows that most JV manufacturers had average curb weight above the fleet average, except for SAIC-GM-Wuling at 985 kg. Among six Chinese independent automakers, only Great Wall had curb weight heavier than the average. The heaviest was Guangqi-Honda at 1,418 kg.

7.1.3 Power and torque

Figure 7.4 shows that most JV manufacturers had power equal to or higher than the fleet average. SAIC-GM-Wuling was an exception, with the smallest average power of 44 kW, which is mainly attributed to its dominant minivan sales. All the independent automakers presented power levels below the fleet average. The highest power output was still from Guangqi-Honda, at 111 kW, because it mainly makes larger cars. Figure 7.5 compares the torque, which is quite consistent with the power for major manufacturers.

7.1.4 Max speed, power-to-weight ratio and engine specific power

Figure 7.6 to 7.8 compare max speed, power-to-weight ratio, and engine specific power. Most JV manufacturers had max speed higher than the fleet average, except for SAIC-GM-Wuling, which had the lowest max speed among major manufacturers (108 km/h). All Chinese independent automakers had max speed lower than the fleet average.

Tianjin-FAW-Toyota had the highest max speed of 201.2 km/h, and both Guangqi-Honda and Tianjin-FAW-Toyota had the highest power-to-weight ratio, 78 W/kg.

SAIC-GM-Wuling had the lowest power-to-weight ratio of 44 W/kg, followed by Chang'an at 49 W/kg. Again, one of the main reasons for this might be because these two manufacturers mainly sell lower-performing minivans. These two manufacturers also had significantly lower engine specific power when compared to others, reinforcing the fact that minivans have adopted few advanced engine technologies. Joint ventures such as Shanghai-GM, Guangqi-Honda, and Tianjin-FAW-Toyota delivered relatively higher engine specific power than others.

7.1.5 Fuel consumption[31]

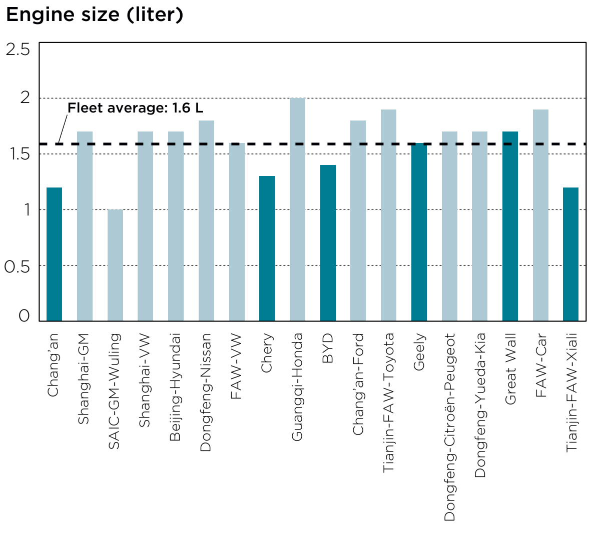
Figure 7.8 compares the combined FC, showing that Guangqi-Honda had the highest fuel consumption of 8.2 L/100 km and Tianjin-FAW-Xiali had the lowest, at 6.5 L/100 km. Among 18 major manufacturers, eight had combined FC above the fleet average.

31 Corporate-average fuel consumption rates from this study are based on an independent data source, and our values should not be considered as official. We noticed slight to moderate differences in CAFC values for certain manufacturers from other sources such as "China Passenger Car Vehicle Corporate Average Fuel Consumption Trend Report of 2010 (Ma et al.; 2011)," May 2011. We believe this is mainly caused by raw data differences, so we do not discuss this issue further in this paper.

7.1.6 Vehicle price and size

Regarding the vehicle price, Figure 7.9 shows the significant difference among major manufacturers. In general, manufacturers dominated by minicars, small cars or minivans – such as Chang'an, SAIC-GM-Wuling, Chery, and Tianjin-FAW-Xiali – had a lower price and smaller footprint when compared to the fleet average. Guangqi-Honda had the most expensive price of $29,322, followed by Tianjin-FAW-Toyota at $24,599, indicating the high price of Japanese-brand cars in the Chinese domestic market.

Most JV manufacturers sold their cars at a price significantly higher than the fleet average, except for South-Korea-brand-based JV manufacturers such as Beijing-Hyundai and Dongfeng-Yueda-Kia.



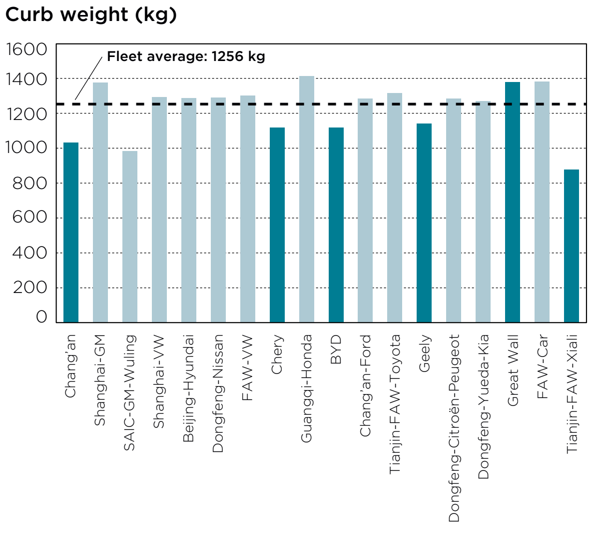


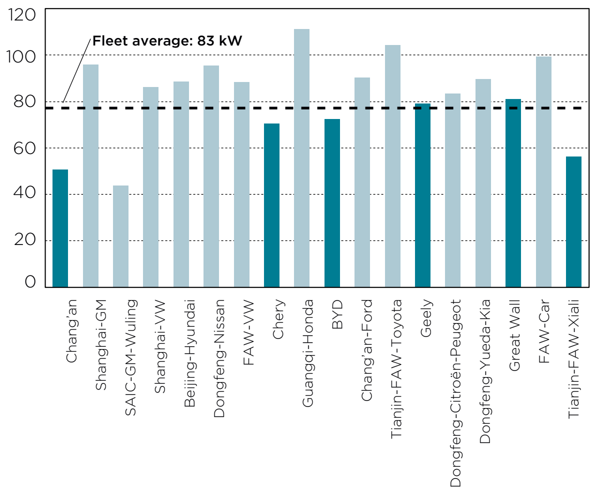
Figure 7.2

Corporate-average engine size by major domestic manufacturer

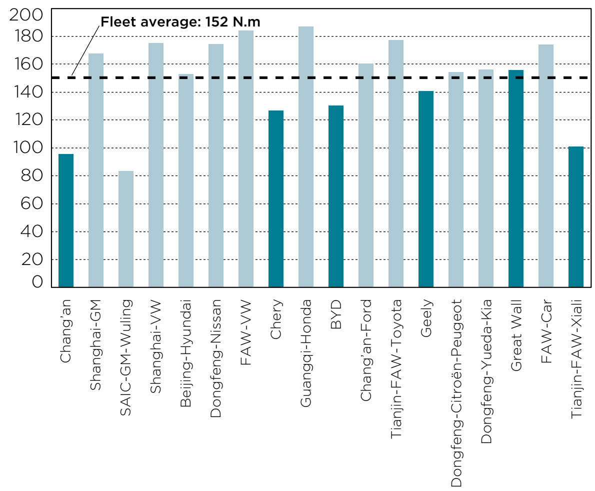
Figure 7.3

Corporate-average curb weight by major domestic manufacturer

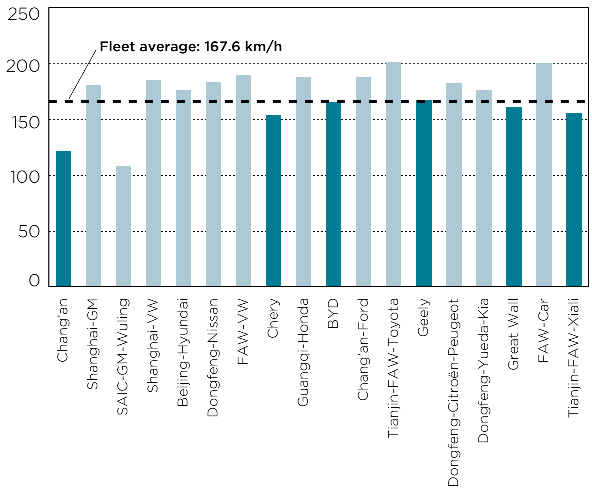
Power (kW)



Torque (N.m)



Max speed (km/h)



Power-to-Weight Ratio (W/kg)

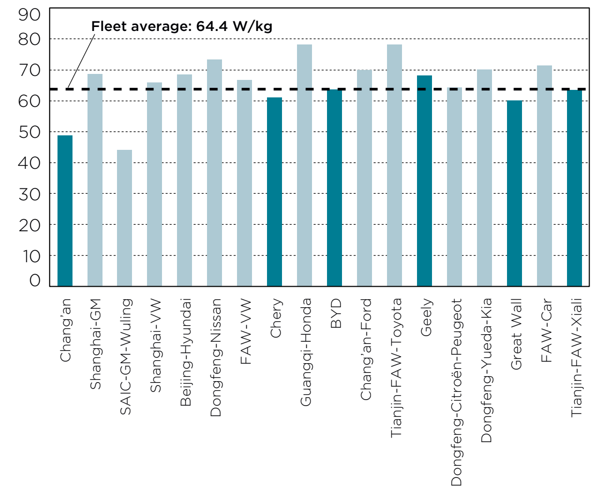


Figure 7.4

Corporate-average engine power by major domestic manufacturer

Figure 7.5

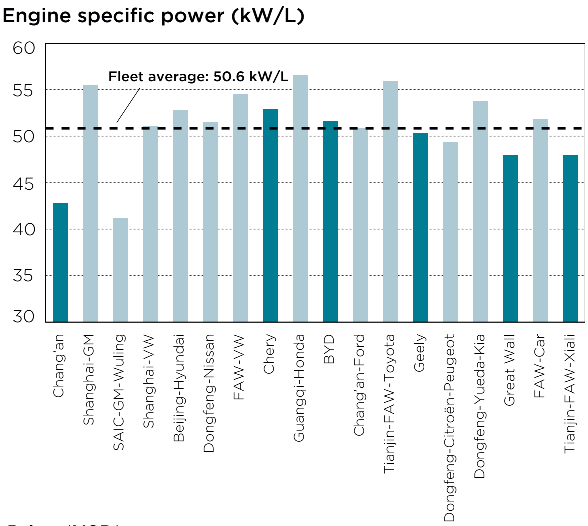
Corporate-average torque by major domestic manufacturer

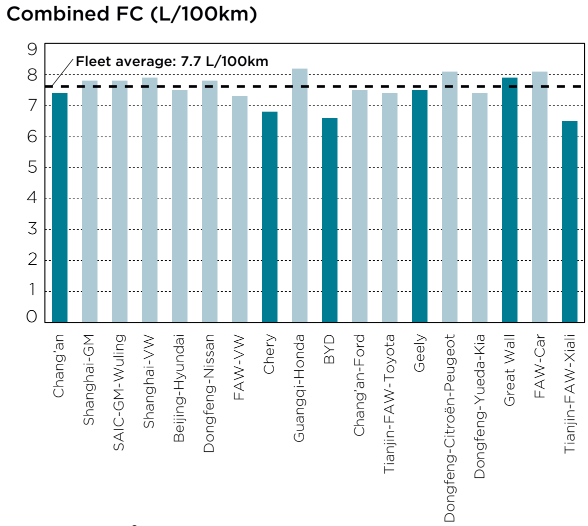
Figure 7.6

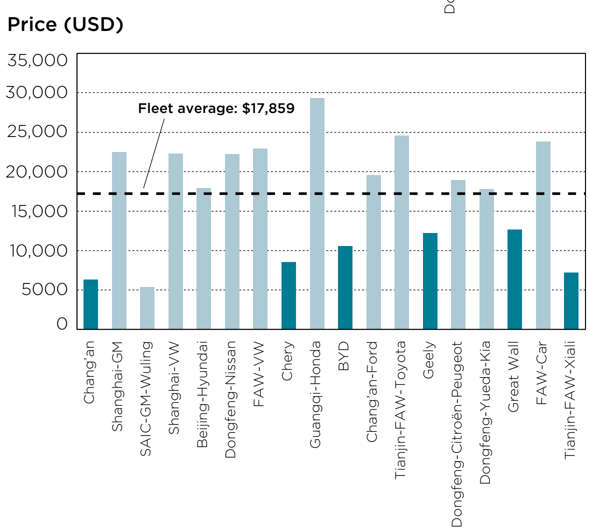
Corporate-average max speed by major domestic manufacturer

Figure 7.7

Corporate-average power-to-weight ratio by major domestic manufacturer







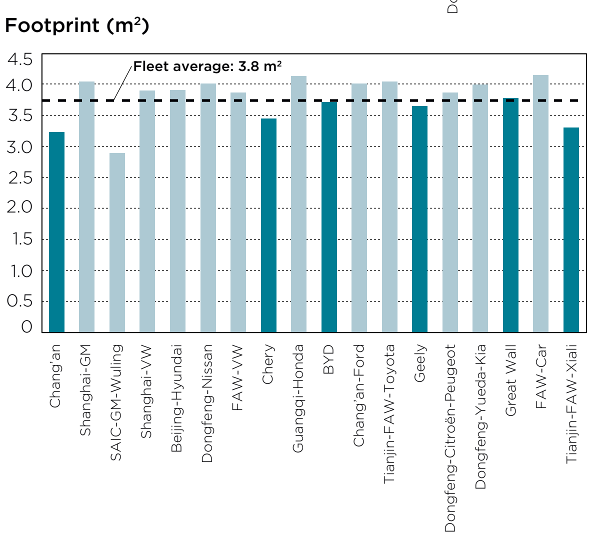


Figure 7.8

Corporate-average engine specific power by major domestic manufacturer

Figure 7.9

Corporate-average combined FC by major domestic manufacturer

Figure 7.10

Corporate-average price by major domestic manufacturer

Figure 7.11

Corporate-average footprint by major domestic manufacturer

Figure 7.12 shows the corporate-average fuel consumption (CAFC) values (in L/100 km) of each major manufacturer as a function of their corporate-average curb weight (in kg) and as a function of their corporate-average footprint (in sq m), and their sales volume (indicated by the size of the bubbles). It also compares each manufacturer's CAFC against the domestic fleet average fuel consumption (dashed line) and the Phase 3 fleet-average fuel consumption target (dotted line). Except for Great Wall (which mainly produces SUVs), all Chinese independent manufacturers are below the current national average fuel consumption level of 7.7 L/100 km. Notably, Tianjin-FAW-Xiali, BYD and Chery's current CAFC values are below the fleet-average target of 6.9 L/100 km required in the Phase 3 standard. However, given that the Phase 3 standard is weight-based, the three auto manufacturers are actually facing lower CAFC targets given the relatively light vehicle weight of their fleets.

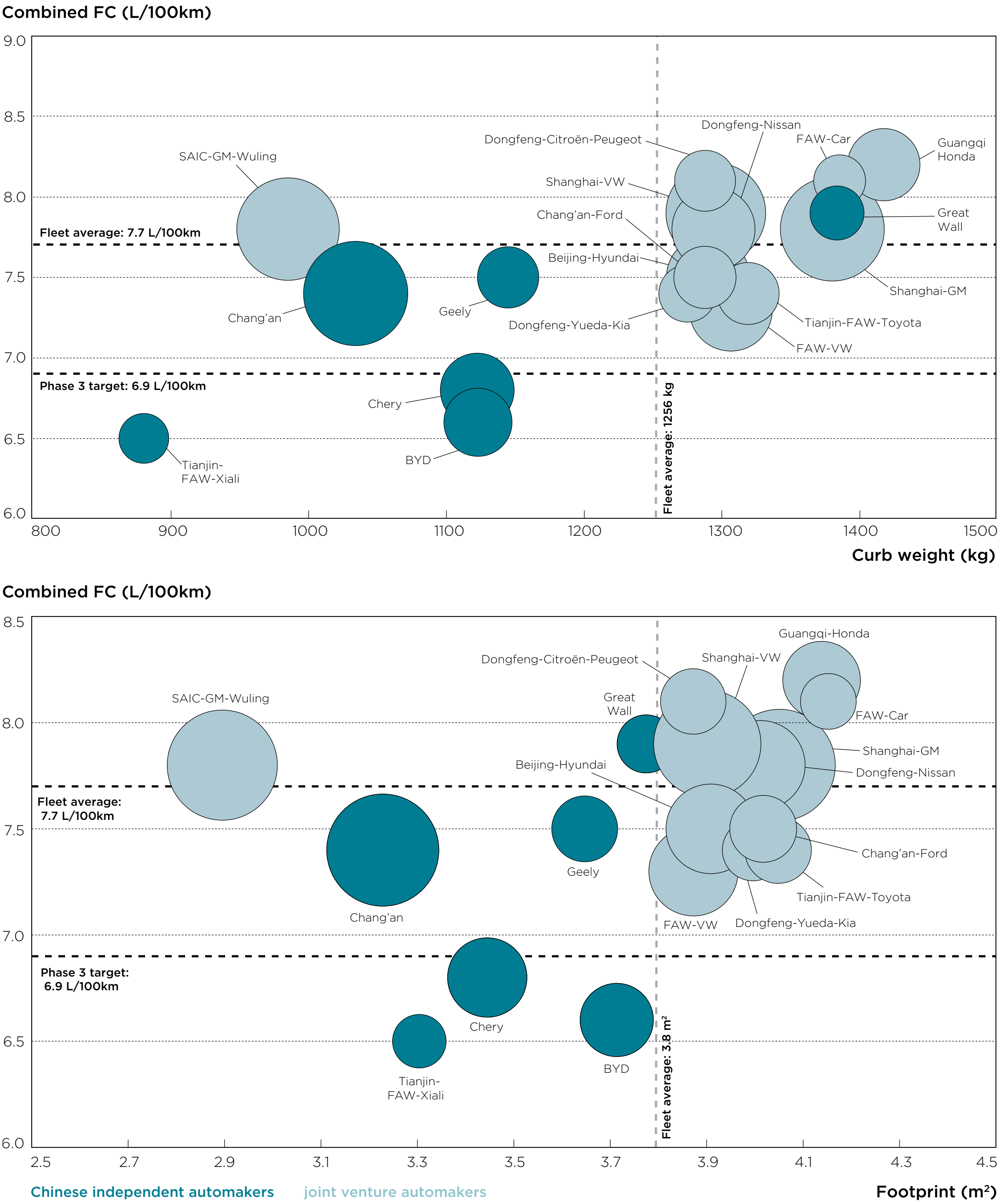
Again, to illustrate the differences between Chinese independent manufacturers and joint venture companies, two different shades are applied to the two types of auto companies.

It is evident that most Chinese independent automakers made lighter and smaller cars than those of JV manufacturers.

When the lower chart (footprint) is compared to the upper chart (curb weight), the relative positions of two of the top three manufacturers, SAIC-GM-Wuling and Chang'an, have moved forward to become the leading positions because of their smaller fleet-average footprint compared to others. Both manufacturers mainly produce minivans.

Figure 7.12

Combined FC vs. curb weight and footprint of major domestic manufacturers



7.2 Technology adoption by manufacturers

7.2.1 Engine technologies

Figures 7.13 to 7.20 show different engine technologies adopted by major manufacturers, with Chinese independent automakers and JV automakers separated to illustrate their differences. Most cars were powered by gasoline; Great Wall sold 4% diesel cars and BYD sold 417 units of Dual Mode Comfort hybrids. Guangqi-Toyota also made the hybrid Camry, but it is not among the selected major manufacturers.

Regarding valve configuration, most manufacturers had a high percentage of DOHC engines, except Chang'an and SAIC-GM-Wuling, which used mostly single overhead camshaft (SOHC) engines (as mentioned, both manufacturers sell mostly minivans, which in general are equipped with SOHC engines). Similarly, these two manufacturers also show large shares of engines with two valves per cylinder and single-point injection, while others sold mostly cars with multi-valve and multipoint injection technologies.

Regarding fuel supply systems, three JV manufacturers adopted GDI technology: Shanghai-GM at 8%, Shanghai-VW at 26%, and FAW-VW at 36%. Geely sold some Volvo S80s with GDI in 2010, but other than that there were no other Chinese independent manufacturers adopting the technology.

For air intake technologies, Figure 7.18 shows that most manufacturers still used naturally aspirated engines, although there were six major manufacturers that employed turbochargers on a percentage of their cars: Chang'an at 1%, Shanghai-GM at 2%, Shanghai-VW at 26%, FAW-VW at 36%, Geely at 3%, and Great Wall at 4%.

Except Shang-GM-Wuling, most JV manufacturers adopted variable valve timing, while four out of six Chinese independent automakers – Chang'an, BYD, Great Wall, and Tianjian-FAW-Xiali – did not. Chery was the leading Chinese automaker in adopting VVT, using it in 11% of its cars. Most manufacturers didn't use variable valve lift. Japanese brand JV manufacturer Guangqi-Honda was an exception, using DVVL (VTEC) on all of its cars, and FAW-VW and Geely adopted it on a small portion (below 6%) of their fleets.

Figure 7.13

Share of engine types by major domestic manufacturer

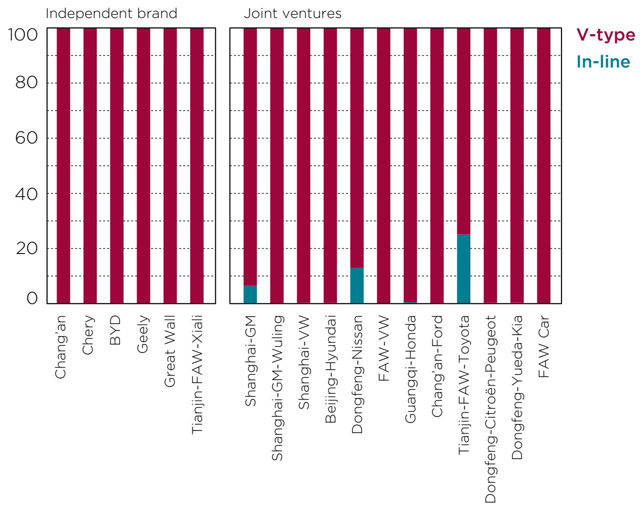
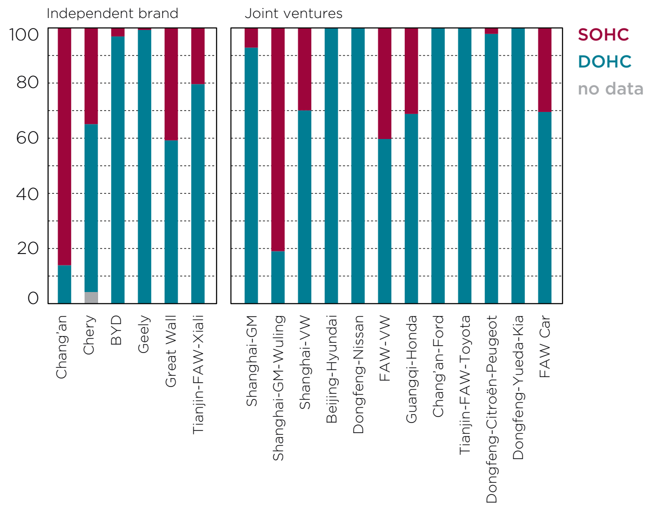


Figure 7.14

Share of valve configuration types by major domestic manufacturer



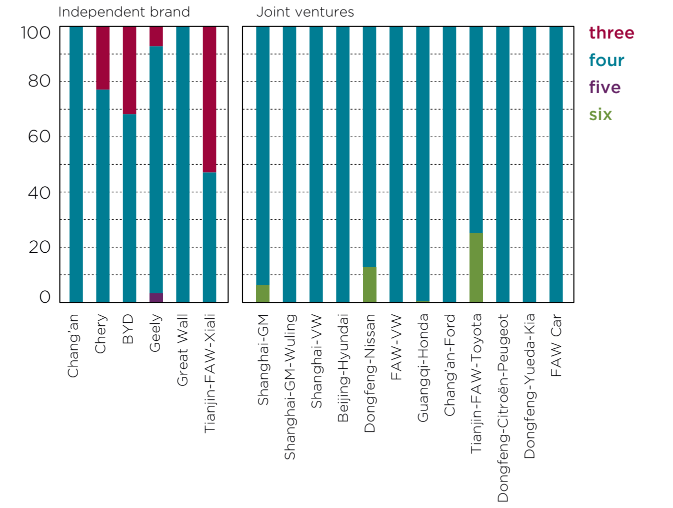


Figure 7.15

Share of number of cylinders by major domestic manufac-turer

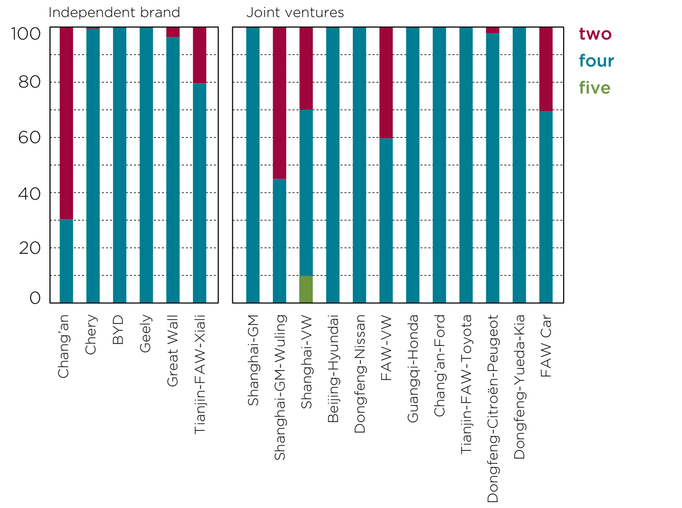


Figure 7.16

Share of number of valves per cylinder by major domestic manufacturer

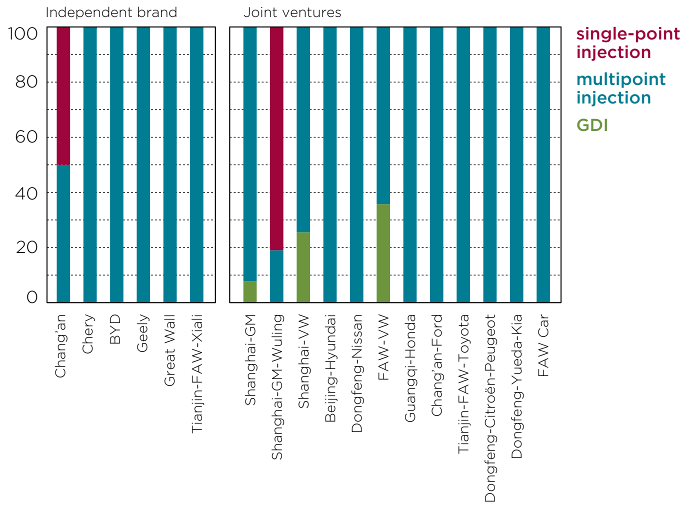


Figure 7.17

Share of fuel supply technologies by major domestic manufacturer

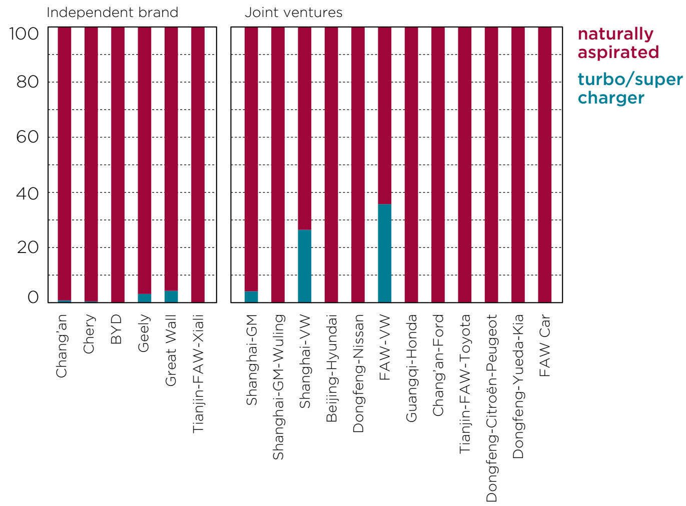
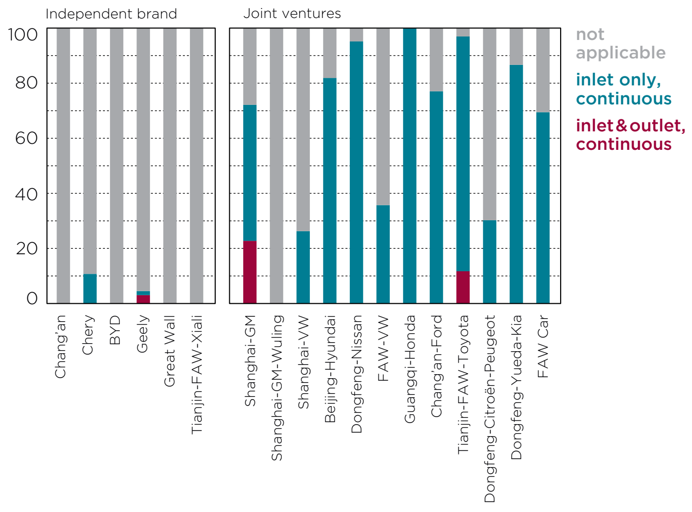


Figure 7.18

Share of air intake technologies by major domestic manufacturer



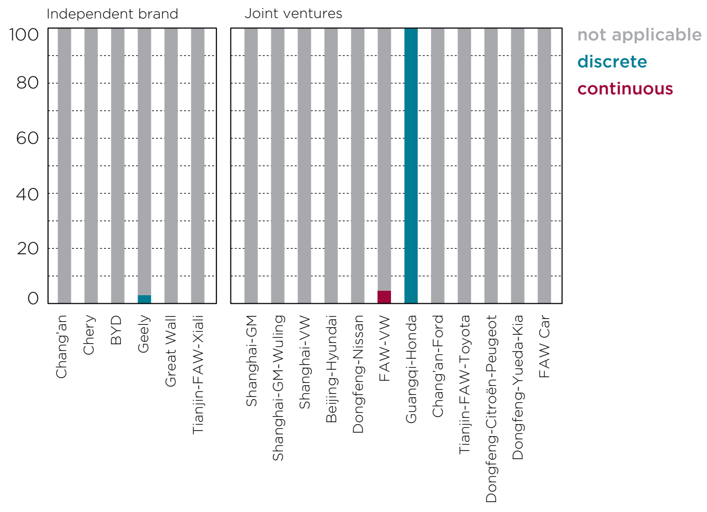


Figure 7.19

Share of valve timing technologies by major domestic manufacturer

Figure 7.20

Share of valve lift technologies by major domestic manufacturer

7.2.2 Transmissions and drivetrain technologies

Figure 7.21 and 7.22 compare transmission technology adoption. Most manufacturers sold cars with five-speed manual transmission.

Among major manufacturers, only two adopted dual clutch: Shanghai-VW (1%) and FAW-VW (11%); they were also the only two to use seven-speed transmissions. All other JV manufacturers adopted six-speed. Among Chinese independent automakers, Chery, Geely, and Great Wall used six-speed transmission on less than 5% of their cars. This might be because most of the cars they manufacture are manual transmission.

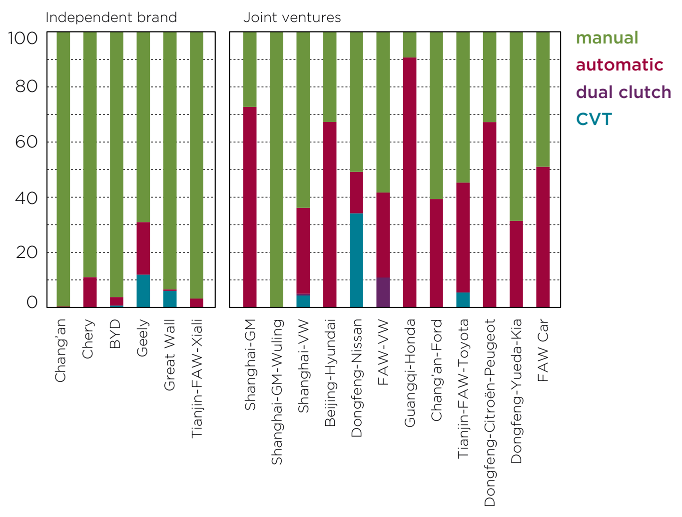
In terms of drivetrain technologies, passenger vehicles with front-wheel-drive (FWD) dominated the market, followed by rear-wheel-drive (RWD), most of which (about 79%) were minivans. A few manufacturers, such as Guangqi-Honda and Great Wall, made 4WD vehicles and about 96% of those were SUVs (Figure 7.23).

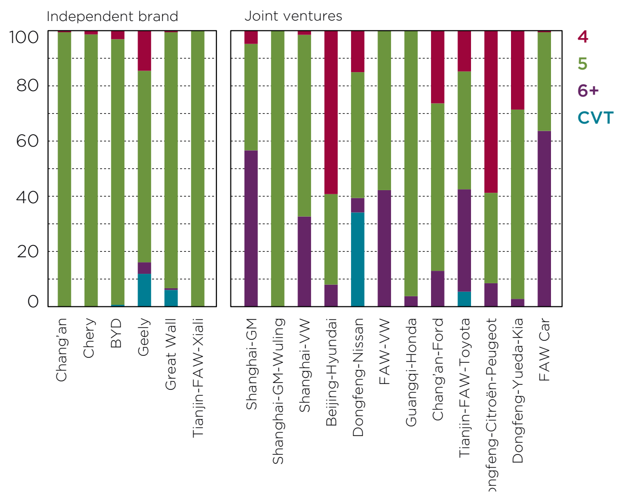
Figure 7.21

Share of transmission types by major domestic manufacturer

Figure 7.22

Share of transmission gear counts by major domestic manufacturer





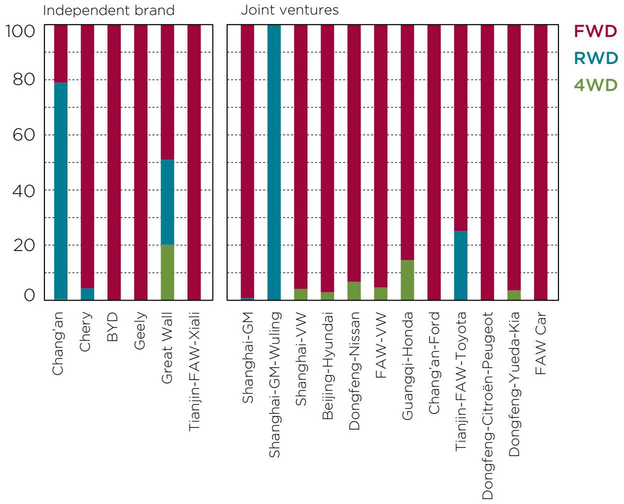


Figure 7.23

Share of drivetrain types by major domestic manufacturer

7.3 Chinese independent automakers vs. joint venture automakers

The analyses of vehicle properties and technology adoption rates of each individual manufacturer in the previous sections show a general trend that compared to JV automakers, most Chinese independent auto manufacturers produced smaller, lighter, lower-performance vehicles that also consume less fuel. Adoption rates of major efficiency technologies are also in general lower among Chinese independent automakers than JV automakers.

However, these analyses do not give an apples-to-apples comparison, given that the product mix of these manufacturers varies to a great extent. With the following case study, we try to compare a set of Chinese independent automakers and JV automakers with similar fleet characteristics and product mix, and competing in similar market divisions, to illustrate differences in efficiency technology status between them.

7.4 Geely vs. Chevrolet vs. VW

Zhejiang Geely Automobile Holdings Ltd. (Geely Group) is the 13th largest passenger car manufacturer and the fourth largest Chinese independent passenger car automaker in 2010, representing about 6% of total passenger car sales in that year according to our data source. The group focuses on small and lower medium car segments although its production line, after merging with Volvo in 2008, extends to medium and large cars as well. Major models under Geely include King Kong (20% of Geely's annual sales in 2010), Emgrand (19%), Panda (15%), Free Curiser (14%), Haijing (14%) and Gleagle (12%). We exclude the Volvo models when conducting this analysis in order to illustrate the status of Geely's self-developed technologies.

The American brand Chevrolet, produced in China by General Motors joint venture Shanghai-GM, has a very similar product mix to Geely (Table 7.24). Major models include the Cruze (35% of Chevrolet's annual sales in 2010), Sail (24%), Lova (16%), Spark (14%) and Epica (10%).

The German brand Volkswagen, produced in China by joint venture FAW-VW, as shown in Table 7.24, produces more large cars than Geely. But its fleet-average vehicle features are the closest to those of Geely among European JV companies in China. Major models include the Jetta (34%), Bora (26%), Sagitar (17%), Magotan (12%), and Golf (9%).

Table 7.24

Market breakdown for Geely, Chevrolet, and FAW-VW

	Mini	Small	Lower medium	Medium	Others	Total
Geely [1]	15%	51%	33%	0%	1%	100%
Chevrolet [2]	14%	41%	35%	10%	0%	100%
VW [3]	0%	0%	85%	12%	3%	100%

[1] Geely refers to Geely Group, excluding Volvo

[2] Chevrolet is produced by Shanghai GM

[3] VW is produced by FAW-VW and excludes Audi

As introduced in Section 4, price, in addition to size, is a major factor that determines the vehicle segmentation in China. The boundaries between car classes (especially between smaller car classes) sometimes can be fuzzy. In Geely's case, the size and other key vehicle features of some of its high-selling models, such as the King Kong, are closer to those of lower medium cars even though they are categorized as small cars due to their cheaper prices. From this perspective, Geely and VW (whose cars are made in China by FAW-VW) are considered comparable, despite the difference in their labeled market segment focuses.

Figure 7.25 compares the average fleet characteristics such as curb weight, engine size, size in terms of footprint, engine specific power, power-to-weight ratio, and fuel consumption rating (first row), as well as the adoption levels of a variety of efficiency technologies (second row) among Geely, Chevrolet, and VW. As shown, with smaller size and lower engine specific power, Geely's average fuel consumption level is even higher than that of Chevrolet and VW. However, in terms of power-weight ratio, Geely's vehicles do offer better power performance than the other two brands.

On the technology side, Geely has significantly lagged behind either one or both of the US and EU brands on almost all technologies analyzed in this study, reinforced by Geely's lower engine specific power value. As mentioned previously, an EPA study (US EPA, 2012) shows that the engine specific power value might be indicative of adoption level of engine technologies. In particular, while VVT and higher gear-ratio transmission systems have been widely adopted in both the VW and Chevrolet fleets, they are still underdeveloped in the Geely fleet. A highlight of Geely, on the other hand, is that its CVT adoption level is much higher than the other two brands.

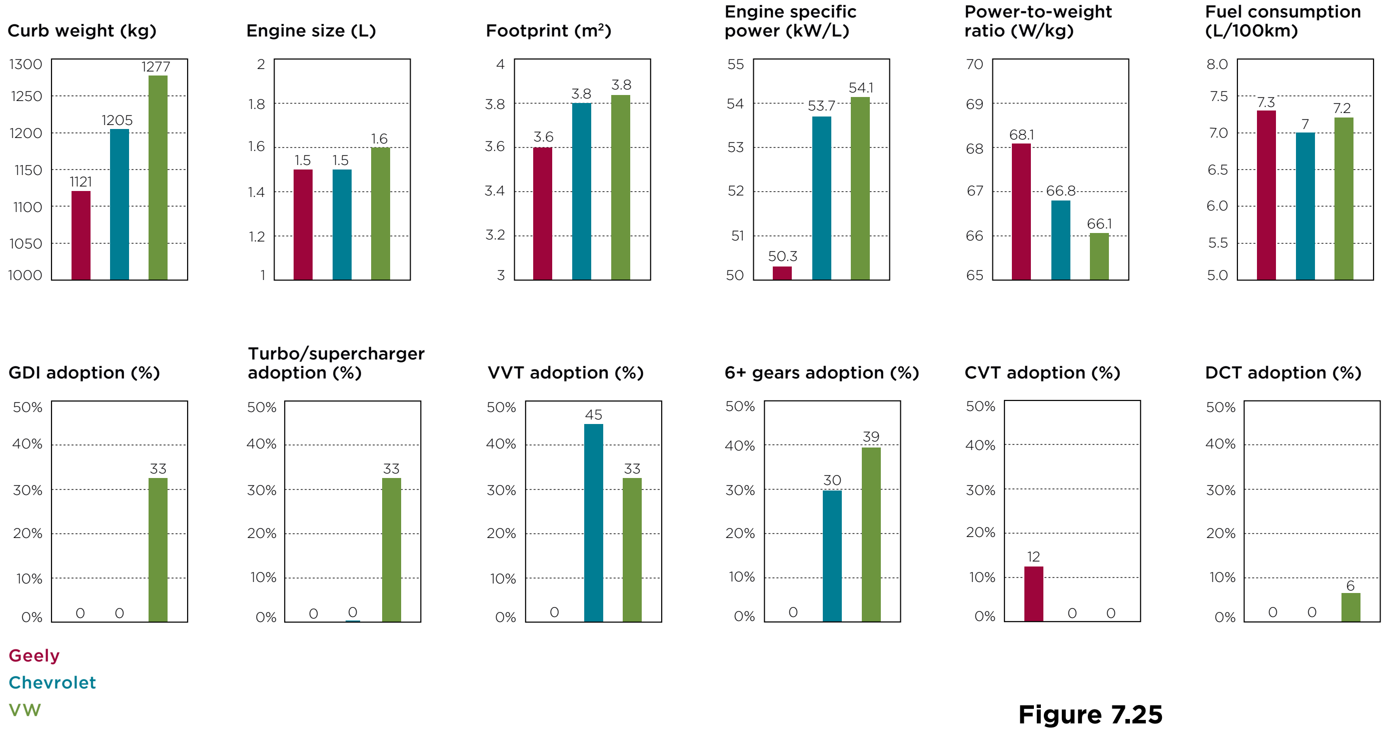


Figure 7.25

Comparison of fleet-average characteristics, adoption of efficiency technologies, and fuel consumption among Geely, Chevrolet, and VW

7.5 Summary

The majority of domestic passenger cars were made by JV manufacturers. JV and Chinese independent automakers focus on different market segments. JV automakers penetrate through nearly all segments, from mini to large and luxury cars and SUVs, but their primary focuses are lower medium and above car segments. Domestic automakers still cluster in the minicar, small car, and minivan segments.

In general, JV automakers have adopted more advanced efficiency technologies than Chinese independent automakers. Many commonly used engine technologies by joint ventures, such as variable valve timing, are still in the early development stage among Chinese independent automakers. However, a new trend of international merging and acquisition led by Chinese independent automakers may change this pattern in the future. For example, by acquiring the Volvo line, Geely has been able to adopt more turbocharging and VVT and may potentially expand implementation of those technologies in its own brands in the future.

Even though Chinese independent automakers were behind on technology adoption, the overall fuel economy of cars made by them was better than that of cars made by joint venture companies. This is because their cars were smaller, lighter, had smaller engine sizes, and had on average lower performance. There is significant room left for them to further improve their fuel efficiency.

8 CONCLUSIONS AND POLICY RECOMMENDATIONS

Based on the above detailed comparative analysis among market segments, major regions, between import and domestic fleets, and among major manufacturers, we have the following findings and recommendations.

8.1 By-segment analysis

Fleet characteristics

– Except for minivans, most of the segments in China's passenger car market were similar to their EU counterparts in terms of average engine displacement, curb weight, and footprint. However, due to the lag in technology adoption by the Chinese fleet, European cars in each major segment had better performance features such as power, max speed, power-to-weight ratio, and engine specific power. What's more, the fuel economy of Chinese cars of each segment was worse than their European counterparts.

– The mini car segment was dominated by domestic brands, and the small car segment shows the roughly equal shares between domestic and foreign brands. Compared to minicars, small cars show significantly improved performance, with 42% increased power and 20% increased power-to-weight ratio, but also 5% higher fuel consumption.

– The lower medium segment was the largest in both the Chinese and EU markets, with 32% of market share. This segment was the closest to the domestic fleet average in terms of vehicle characteristics. From this segment upward, JV manufacturers dominated the market, producing more than 90% of medium and large cars.

– Chinese customers favored smaller SUVs, and the SUV market was dominated by foreign brands.

– The minivan segment was the second largest segment. On average, minivans have the smallest footprint, the lowest cost, and the poorest utility performance in terms of output power, max speed, power-to-weight ratio, and engine specific power. Their average curb weight and engine size are similar to that of minicars, yet their fuel consumption was only comparable with the lower medium segment.

Technology adoption

- Gasoline-powered cars dominated all segments by market share, ranging from 94–100%. Most diesel cars were SUVs. The gasoline-diesel split was different from the EU market, where diesel cars from the lower medium to larger car segments (including SUVs) had a major share.

- Most of the segments were equipped with manual transmission with no more than five gears. The deployment of fuel efficiency technologies varied to a great extent by segment. More advanced technologies were used in larger cars than smaller cars. Overall, the minivan segment showed a lag in technology adoption compared to other segments.

- On average, of the majority of the car segments, European cars show higher market penetration of major efficiency technologies such as turbo- or super-charging and higher gear transmission (six-speed or above) than their Chinese counterparts.

8.2 By-region fleet analysis

- When compared to the EU and US, the Chinese fleet had the higher sales volume and the lower fleet-average price.

- Most vehicle characteristics of China's fleet, such as engine size, curb weight, footprint, power, power-to-weight ratio, and fleet average fuel consumption, were between the levels of the EU gasoline cars and US cars. An exception was that the Chinese fleet shows the lowest value in max speed and engine specific power.

- For certain vehicle fuel efficiency technologies, the adoption rates in China are comparable to either the EU or US (for example, the adoption of gasoline direct injection is close to that in US, but much lower than that of the EU), but for the majority of the technologies analyzed in this report China lagged behind the other two markets. However, we admit that due to data limitations for certain efficiency technologies, we cannot draw similar conclusions on technologies that are not included in this report (such as cylinder deactivation).

8.3 Comparison between import and domestic fleet

Fleet characteristics

- Imports captured only 4.2% of the market and were primarily larger, more powerful, luxury, gas-guzzling, and expensive. Nearly half of the import fleet was fuel-consumptive SUVs.

- Due to the prevalence of premium SUVs, luxury, and sports cars of larger engine size, the import car fleet also had the broader range of fuel consumption than the domestic fleet, indicating a variety of customer demands.

Technology adoption

- Engine technologies such as multivalves, double overhead camshaft (DOHC), and multipoint injection, were found to be widespread in the domestic fleet. Advanced technologies such as gasoline direct injection, turbocharging, and hybrid technologies have been introduced in the market, but have not penetrated across the fleet.

- Nearly 60% of the domestic fleet was equipped with manual transmissions while most of the import fleet was equipped with automatic transmissions. Dual clutch transmissions have started to emerge in both fleets. Five-speed manual transmission was commonly employed in the domestic fleet, while six-speed automatic transmission was mainly employed in the import fleet.

- The import fleet more consistently achieved the Euro 4 emissions standard than the domestic fleet. All import SUVs met the Euro 4 standard, but 6% of the domestic SUVs still had not.

- Overall, more advanced engine and transmission technologies were found in the import fleet, but they were used to boost utilities rather than fuel economy.

8.4 Comparison among major domestic manufacturers

Fleet characteristics

- The top 18 manufacturers (collectively holding over 80% of the market share) were selected for analysis; most of them were JV manufacturers. Chang'an, dominated by minivans, had the largest market share (about 8%), closely followed by Shanghai–GM, SAIC–GM–Wuling, and Shanghai-VW.

- In general, Chinese independent auto manufacturers produce smaller, lighter vehicles than JV automakers. Also the fuel consumption rates in absolute terms of Chinese independent automakers' models are lower than those of JV automakers. However, this is mainly due to the smaller size of the independent brand vehicles.

Technology adoption

- In general, JV automakers adopt more advanced efficiency technologies than Chinese independent automakers. However, a new trend of international merging and acquisition led by Chinese independent automakers may change this pattern in the future.

- A significant technology gap was found between Chinese independent brands and international brands of the similar fleet characteristics and product mix in the market from our case study.

8.5 Policy recommendations

Based on the above general findings, we provide the following preliminary policy recommendations for future passenger car fuel consumption regulations:

- Stringent regulatory standards are needed to drive technology innovation and upgrade, and therefore to enhance the competitiveness of the Chinese auto industry.

- The current policy (or lack of effective policy) on import car fuel consumption fails to bring world-class efficient vehicles into the Chinese market. Future regulations should set the same noncompliance penalties for gas-guzzling imports as for domestic vehicles. Special incentives that encourage the importation of super-efficient vehicles can be considered.

- Given that the advanced technologies in larger car segments are more market-ready, future standards can be designed to be more stringent on bigger and heavier vehicles than on small cars.

- Special incentives are needed to improve the efficiency of minivans or to replace the segment with more efficient but similarly functional vehicles.

- Flexibilities and incentives may be needed to allow some Chinese automakers that are behind on technology adoption and have relatively narrow product lines to be able to meet the future stringent standards within a reasonable range of cost increases.

ANNEX

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Efficiency technologies

Energy efficiency

In general, when a vehicle is moved forward, fuels are burned. Energy is released from the chemical reaction occurring in the combustion chamber, then converted to mechanical work to move the vehicle forward through the drivetrain components. This series of processes occurs fast, but does result in energy loss. This section will briefly introduce energy loss with data based on the US government's fuel economy website. Energy loss can be divided into four categories: engine losses, parasitic losses, power to wheels losses, and drivetrain losses. Of these, the engine losses have the major share, up to 74%, followed by power to wheel losses of 17%–21%.[32]

32 Fuel Economy: Where the Energy Goes. Retrieved from http://www.fueleconomy.gov/feg/atv.shtml

Engine losses

The majority of modern vehicles are still based on internal combustion engines (ICE) and burn gasoline (spark ignition) or diesel (compression ignition) fuels. When fuel is burned, not all of it will be converted to mechanical energy. Instead, most of the energy will be released as heat loss. Another small portion of engine loss is attributed to mechanical friction, air blow-by, and efficiency of combustion. To address these issues, engine technologies such as variable valve timing and lift, turbocharging and downsizing, and direct fuel injection have been used.

Power to wheels losses

Based on the vehicle dynamics, the acceleration speed of a vehicle depends on three components besides mass: vehicle power required, aerodynamic or wind resistance/drag, and rolling resistance. Vehicle power will be less than the engine output power through the drivetrain losses. In terms of aerodynamic drag, the design of a vehicle's front is critical. A streamlined shape could dramatically reduce wind resistance. Rolling resistance is attributed to the contact between the tires and road. Low resistance tires could be used to reduce the energy loss. Another loss comes in braking; heat is released when brake pads come into contact with the rotors. Hybrid vehicles could use the heat created by braking to regenerate energy.

Drivetrain losses

The power output from the engine is transferred to the wheels through the transmission. A transmission with optimum gear ratios, such as dual clutch, continuous variable transmissions, etc., could significantly improve efficiency.

Parasitic losses

When a vehicle is moving, beside the above energy losses, it also has losses from auxiliary components, such as driving belts, air conditioning, the water pump, power steering, etc. For example, fuel economy may be substantially different when air conditioning is on or off, even under the same road conditions. An improved alternator or power steering could be used to slightly reduce fuel consumption.

Efficiency technologies

Due to the energy losses mentioned in the above section, advanced technologies have been developed to reduce greenhouse gas (GHG) emissions and vehicles' fuel consumption. These fall into the following categories: engine technologies, transmission technologies, hybrid technologies, accessory technologies, and vehicle technologies. Government agencies, organizations, and academic institutions have conducted numerous studies to investigate the reduction potential and costs associated with these technologies.

Table A-1 briefly introduces these technologies with descriptions and their potential to reduce fuel consumption or CO_2 emissions from light-duty vehicles based on reports by the EPA/NHTSA (EPA/NHTSA, 2010, EPA/NHTSA, 2012). The 2010 EPA/NHTSA report estimated technology cost and potential in the MY 2012–2016 time frame, while the 2012 EPA/NHTSA report provides estimates for the MY 2017–2025 timeframe. Some emerging technologies on the current market might be become prevalent in the MY 2017–2025 time frame, such as P2 hybrid technology, due to its relatively lower cost and higher efficiency compared to power-split or two-mode hybrids (EPA/NHTSA, 2012).

The benefit data values in Table A-1 represent the percentage reduction based on base vehicles or engines. A baseline usually refers to a base vehicle equipped with four-speed automatic transmission, a naturally aspired gasoline engine with fixed valve timing and lift, and port-fuel injection.

Some of technologies listed are not available in the raw database of China's passenger vehicles, such as cylinder deactivation, most hybrid technologies, vehicle technologies, and accessory technologies.

Table A-1

Technologies and their potentials to reduce CO_2 emissions and fuel consumption

Technologies	Description[a]	Effect (%)[a]
Engine technologies		
Low friction design and materials	Includes low-friction lubricants and optimize the engine design to reduce engine friction to improve fuel economy.	0.5–4.0[b]
Gasoline direct injection (GDI)	High-pressure fuels are directly injected into combustion chamber. As a result, temperature of the air/fuel charge is reduced and higher compression ratios can be achieved without knocking. Consequently, thermodynamic efficiency is increased.	1.5
Turbocharging and downsizing	Turbocharging increases the intake manifold pressure and airflow. As a result, the specific power level will be increased, and engine displacement can be downsized without compromising the performance. Engine size can be reduced by 30% at similar power output.	12.0–24.6[c]
Cooled exhaust gas recirculation (EGR)	Increases exhaust gas recirculation to control combustion temperature and reduce fuel consumption and emissions.	5.0[d]
Diesel technologies	Converts to diesel engine with after-treatment technologies such as lean NO_x trap (LNT) or selective catalytic reduction (SCR) to reduce fuel consumption and emissions.	28.4–30.5
Variable valve timing (VVT)	Optimizes timing of intake/exhaust valves, or both to reduce the pump losses at different engine speeds while maintaining the power output. Cam phasers are used to optimize the relative angular between camshaft and crankshaft, thus reducing the pump work. Technologies include intake cam phasing (ICP), dual cam phasing (DCP) and coupled cam phasing (CCP).	1.0–5.5
Variable valve lifting (VVL)	Uses different cam profiles and mechanical linkage, respectively, to optimize the lift to reduce the pump losses from throttling, including discrete variable valve lift (DVVL) and continuous variable valve lift (CVVL). CVVL has greater potentials to reduce the pumping losses than DVVL.	1.5–7.0
Cylinder deactivation	When engine is at low loads, cylinders can be deactivated to reduce pumping losses and fuel consumption, because valves are closed and no fuel is injected into the cylinders. This technology is usually applied to engines with six or eight cylinders.	4.7–6.5

Transmission technologies		
Improved automatic transmission control	Optimizes the transmission shift schedule and lock-up torque converter in a wider range of operations to improve the efficiency, such as early torque converter lockup and aggressive shift logic.	0.5–4.3
Dual clutch transmission (DCT) or AMT	Similar to manual transmission but it uses different clutches to control the odd- or even-numbered gears. As a result, the gear ratios can be optimized and smoother shift will be achieved.	4.0–6.0[e]
Continuously variable transmission (CVT)	CVT uses a metal belt rather than fixed gears of automatic or manual transmissions, to provide continuous and variable gear ratios. As a result, vehicles could operate more efficiently in a broader range of conditions.	1.0–6.0
5-speed automatic	With additional gears added, more gear ratios could be used to improve the transmission efficiency.	2.0–3.0
6-speed automatic	Same as above	3.1–3.9
8-speed automatic	Same as above	8.7–9.2[f]
6-speed manual[1]	Same as above	2.0–2.5
Hybrid technologies		
12V BAS micro-hybrid[2]	Most basic hybrid technology, which shuts the engine off when the vehicle is idling or decelerating. This technology employs an improved power starter-alternator. But when the engine is shut off, the hydraulic pressure will be lost. As a result, electric power steering and an auxiliary transmission pump are needed.	4.8–5.9
IMA/CISG[3]	A crankshaft mounted electric motor/generator is connected to the transmission and provides idle-stop and regenerative braking features.	20.0–30.0
Power-split hybrid	The power-split hybrid allows the vehicle to operate at pure electric mode, besides the basic hybrid functions such as idle engine stop, regenerative braking, etc. It uses two motors and the transmission has been replaced with a single planetary gear. This technology achieves greater efficiency in city driving than highway driving, considering more stop-and-go operations by city drivers.	23.0–33.0
Two-mode hybrid	Uses two motors to control the ratios between engine and vehicle speeds, which is similar to CVT. The second motor increases the cost of this technology.	23.0–33.0
P2 hybrid	A transmission-integrated electric motor is used between the gearbox and engine. The motor is connected to the engine crankshaft by a clutch. The engine and motor operates independently. It enables vehicles to operate in pure electric mode.	45.1–49.4
Plug-in hybrid	PHEV uses a larger battery pack to store the energy and the battery can be charged from an outside of electricity. Additionally, the improved control system allows the battery to be significantly depleted under electric-only or mechanical/electric modes.	40.1–47.7
Vehicle technologies		
Mass reduction	The vehicle's weight can be reduced using optimum design and lighter materials. As a result, engine output power could be reduced to achieve the comparable level of performance. One of the tradeoffs might be the safety issue of a vehicle with lighter weight.	3.5–5.1g
Aerodynamic drag reduction[4]	Optimizes the body shape of the vehicle, especially the frontal area	2.0–3.0
Low drag brake	Reduces the sliding friction between the brake pads and rotors when the brakes are not engaged	0.8
Low rolling resistance tires[5]	Reduces the energy losses from friction between the tires and contact ground.	1.0–4.0
Accessory technologies		
Electric power steering (EPS)	Reduces the energy losses from the hydraulic pump used by conventional power steering.	1.0–2.0
Improved accessories[6]	Such as improved alternator, water pump, etc. to achieve higher efficiency.	1.2–3.9

a 2010 and 2012 EPA/NHTSA reports

b Low friction lubricants were estimated at 0.5–0.9%; two levels of engine friction reductions were estimated in the 2012 EPA/NHTSA report: level 1 benefit 2.0–2.7%, level 2 benefit 2.83–4.07%

c GDI technology is included and cooled exhaust gas recirculation is also included for the higher boost level

d Incremental to the turbo-charged and downsized engine with direction injectione Relative to baseline AT with the same number of gears; 6-speed DCT relative to 4-speed AT: 7.4–8.6%

f Reduction potentials: 8-speed AT vs. 6-speed AT, 4.9–5.34%; 8-speed DCT vs. 6-speed DCT, 3.85–4.57%; 8-speed DCT vs. 4-speed DCT 11.1–13.1%

g For every 10% mass reduction, effectiveness of 5.1% was estimated, while benefits of 3.5% and 5.1% was estimated for less than and greater than 10% mass reduction, respectively

1 Compared to 5-speed manual

2 Combined with improved accessories level 1 and 2

3 IMA = integrated motor assist; CISG = crank integrated starter generator

4 Aerodynamic drag reduction (10–20%) from level 1; level 2 includes the off-cycle credit and is not included in this table

5 Two levels of low rolling resistance tires estimated by EPA/NHTSA: First and second levels show 10% and 20%, respectively, reduction of rolling resistance

6 EPA/NHTSA considered two levels of technologies: Level 1 effectiveness 1.2–1.8%, and level 2 relative to level 1 1.74–2.55%

In general, a learning effect exists for most technologies. When a technology is newly developed and applied, it will cost more than later, when it is produced in a large volume and becomes widely used. Regarding the learning effect, most technologies show time-based learning effects, which result in a 3% lower cost every year after the first year of introduction of the technology (EPA/NHTSA, 2010). When new technologies are considered, using the volume-based learning effect, EPA estimated a 20% drop in the price every two years after the technology is initially introduced (EPA/NHTSA, 2010). This includes hybrid technologies. Learning effects are not considered for basic technologies that have been widely used on vehicles, such as low rolling resistance tires, low drag brakes, etc. Usually, a technology with low complexity has been widely adopted, while a technology with high complexity is relatively new and will take a long time to become applicable to most of vehicles.

Table A-1 shows that hybrid technologies have the highest benefits while accessories technologies represent the lowest. Among engine technologies, turbocharging, downsizing, and cylinder deactivation are most effective. In terms of transmission technologies, DCT, CVT, and higher-speed transmissions (more than five speeds) have the highest reduction potentials. Most hybrid technologies beyond very basic ones can significantly reduce fuel consumption and GHG emissions. Mass reductions are seen as a result of the most effective vehicle technologies.

Glossary

4WD	four-wheel drive
AT	automatic transmission
AWD	all-wheel drive
CAFC	corporate-average fuel consumption
CATARC	China Automotive Technology And Research Center
CCP	coupled camshaft phasing
CISG	crank integrated starter generator
CNG	compressed natural gas
CO_2	carbon dioxide
CVT	continuous variable transmission
CVVL	continuous variable valve lift
DCP	dual camshaft phasing
DCT	dual clutch transmission
DOC	diesel oxidation catalyst
DOHC	dual overhead camshaft
DPF	diesel particulate filter
DVVL	discrete variable valve lift
EGR	exhaust gas recirculation
EPS	electric power steering
FC	fuel consumption
Flex	flexible fuel
FWD	front-wheel drive
GDI	gasoline direct injection
GDP	gross domestic product
GFEI	Global Fuel Economy Initiative
GHG	greenhouse gases
GVW	gross vehicle weight
ICCT	International Council on Clean Transportation
ICE	internal combustion engine
iCET	Innovation Center for Energy and Transportation
ICP	intake cam phasing
IEA	International Energy Agency
IMA	integrated motor assist
JV	joint venture
LDV	light-duty vehicle
LG	large car
LM	lower medium car
LNT	lean NO_x trap
LPG	liquefied petroleum gas
MD	medium car
MIIT	Ministry of Industry and Information Technology
MN	mini car
MPV	multipurpose vehicle
MV	minivan
MY	model year
NEDC	new European driving cycle
NHTSA	National Highway Traffic Safety Administration
NO_x	nitrogen oxides
PC	passenger car
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
RWD	rear-wheel drive
SCR	selective catalytic reduction
SM	small car
SOHC	single overhead camshaft
SUV	sport utility vehicles
US EPA	US Environmental Protection Agency
VTEC	variable valve timing and lift electronic control
VVL	variable valve lift
VVT	variable valve timing

Abbreviations of auto manufacturers

Bejing-Hyundai	Beijing Hyundai Motor Company Co.
BYD	BYD Co., Ltd.
Chang'an-Ford	Chang'an Ford Mazda Automobile Co., Ltd.
Chang'an	Chongqing Changan Automobile Company Ltd.
Chery	Chery Automobile Co., Ltd.
Dongfeng-Citroën-Peugeot	Dongfeng Peugeot Citroën Automobile
Dongfeng-Nissan	Dongfeng Nissan Passenger Vehicle Co.
Dongfeng-Yueda-Kia	Dongfeng Yueda Kia Motor Co., Ltd.
FAW Car	First Auto Works Car Co.
FAW-VW	First Auto Works Volkswagen
Geely	Geely Automobile Holdings Ltd.
Great Wall	Great Wall Motors
Guangqi-Honda	Guangqi Honda Automobile Co.
SAIC-GM-Wuling	Shanghai Automotive Industry Corporation-General Motors-Wuling Automobile Co.,Ltd.
Shanghai-GM	Shanghai General Motors Co., Ltd
Shanghai-VW	Shanghai Volkswagen
Tianjin-FAW-Toyota	Tianjin First Auto Works Toyota Motor Co.
Tianjin-FAW-Xiali	Tianjin First Auto Works Xiali Automobile Co.
VW	Volkswagen

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