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BRIEFING

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Comparison of fuel-efficiency technology deployment in passenger cars in China, Europe, and the United States

To foster oil independence and mitigate climate change, China, the United States, and the European Union have enacted regulations to reduce the fuel consumption (FC) of light-duty vehicles, such as FC standards and tax incentives. Fuel consumption standards are an effective approach that have been adopted by all three regions. These standards have become increasingly stringent during the past few years, driving manufactures to adopt advanced technology to reduce fuel consumption. This briefing provides insights into the trends of technology deployment in response to the latest standards in China, the U.S. and the EU from 2010 to 2014.

Specifically, this briefing compares the fleet characteristics and vehicle technology deployment in China, Europe and the U.S. from 2010 to 2014. In addition, the briefing evaluates the response of the passenger vehicle market in China to the country's 2014 standard and lays the foundations for future technology development and cost assessments to establish 2025 to 2030 fuel consumption standards.

Prepared by: Huan Zhou, Zifei Yang

OVERVIEW OF FUEL CONSUMPTION STANDARDS IN CHINA

The first-ever fuel consumption standard for passenger vehicles in China (GB 19578-2004) was adopted in 2004[1]. It established both Phase I and Phase II fuel consumption standards, which took effect in 2005 and 2008, respectively. The standards required that each vehicle model comply with fuel consumption regulations before it entered the market.

In addition to specific fuel consumption limits by weight class, the Phase III standards[2], implemented in 2012, set a corporate-average fuel consumption (CAFC) target. In December 2014, the Chinese Ministry of Industry and Information Technology (MIIT) released Phase IV standards that echoed China's Energy-Saving and New Energy Vehicle Industry Development Strategic Plan of 2012-2020[3]. The standards took effect in 2016 and required that the overall fleet-average fuel consumption fall to 5L/100km in 2020 from 6.9/100km in 2015[4].

The Phase IV standards include maximum fuel consumption limits and CAFC standards for manufacturers based on weight distribution across the fleet. Manufacturers were required to meet both; each vehicle model produced should comply with its maximum limit, and the overall fleet should meet the CAFC target. Details of the fuel consumption standards in China are shown in Figure 1.

Made in China 2025, a master strategy for China's future manufacturing released by the State Council, also included longer-term fuel consumption standards. It reinforced the goal of reducing fleet average fuel consumption to 5.0L/100km by 2020 and suggested a fleet-average goal of 4.0L/100km by 2025[5].

1 GB 19578-2004, Fuel Consumption Evaluation Methods and Targets for Passenger Cars (i.e. Phase I and Phase II standards), *Ministry of Industry and Information Technology*, 2004. Retrieved from http://www.transportpolicy.net/index.php?title=China:_Light-duty:_Fuel_Consumption

2 GB 27999-2011, Fuel consumption evaluation methods and targets for passenger cars (i.e. Phase III standards), *Ministry of Industry and Information Technology*, 2011. Retrieved from http://www.sac.gov.cn/SACSearch/outlinetemplet/gjcxjg_qwyd.jsp?bzNum=GB 27999-2011

3 Hui He, Zifei Yang, *China phase IV passenger car fuel consumption standard proposal* (ICCT: Washington DC, 2014). Retrieved from http://www.theicct.org/sites/default/files/publications/ICCTupdate_ChinaPhase4_mar2014.pdf

4 GB 19578-2014, Fuel Consumption evaluation methods and targets for passenger cars (i.e. Phase IV standards), *Ministry of Industry and Information Technology*, 2014. Retrieved from http://www.transportpolicy.net/index.php?title=China:_Light-duty:_Fuel_Consumption

5 State Council, *Made in China 2025*. Document No. 28, 2015. Retrieved from http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm

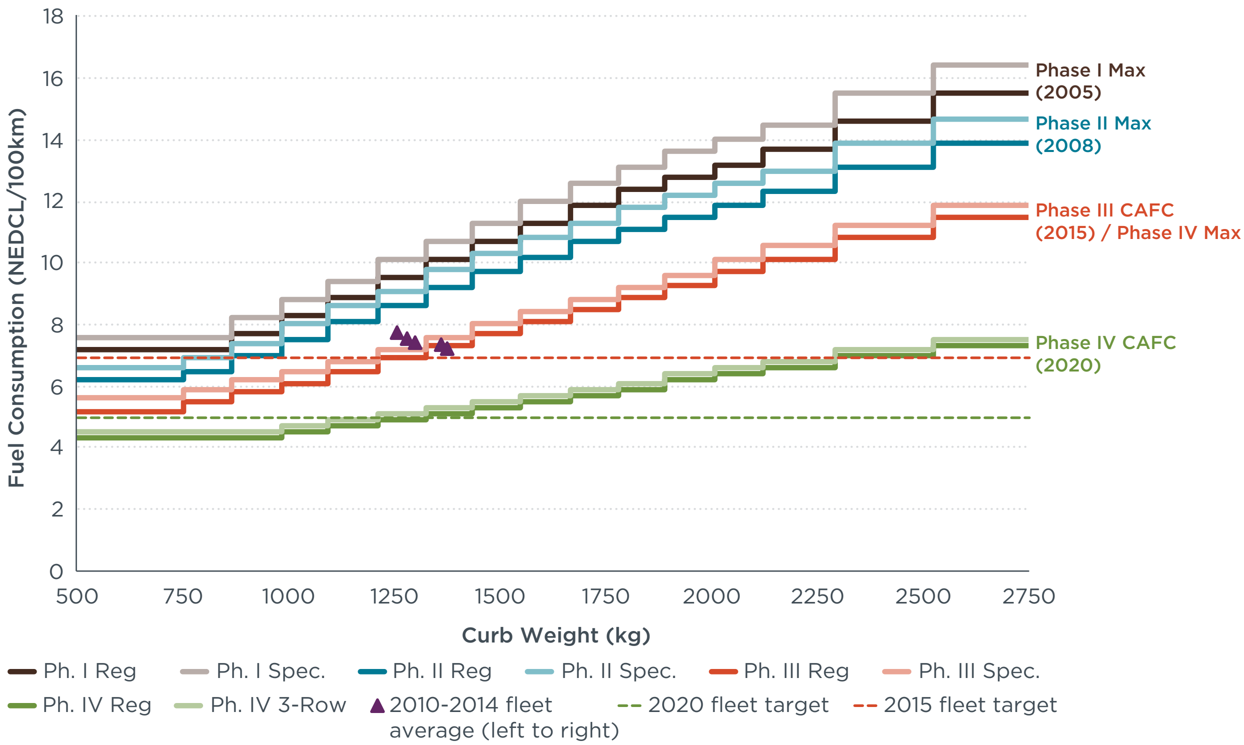


Figure 1. Historic and current fuel consumption standards in China

COMPARISON OF STANDARD STRINGENCY BETWEEN CHINA, THE U.S., AND THE EU

The U.S. light-duty vehicle fleet as defined under the greenhouse gas (GHG) and fuel economy standards includes not only cars and two-wheel drive SUVs with a gross vehicle weight up to 2,700 kg, but also light trucks and two-wheel drive SUVs from 2,700 kg to 4,500 kg, all four-wheel drive SUVs and passenger vans up to 4,500 kg, and all cargo vans and pickup trucks up to 3,900 kg[6]. In China and the EU, the light-duty vehicle fleet includes passenger cars with a gross vehicle weight up to 3,500kg (M1) and light-commercial vehicles up to 3,500kg (N1). Since most light trucks meeting the U.S. Environmental Protection Agency (EPA) definition are regulated as N1 vehicles in China and the EU, which are subjected to a different fuel consumption target, it is more appropriate to compare U.S. cars and two-wheel drive SUVs up to 2700kg with China and EU passenger cars up to 3500kg.

The National Highway Traffic and Safety Administration (NHTSA) and the EPA are the two regulatory agencies responsible for issuing and implementing GHG and fuel economy standards in the U.S. The 2017-2025 corporate-average fuel economy (CAFE)

6 U.S. Environmental Protection Agency (2015). "Trends Report– Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2015," (2015). Retrieved from https://www3.epa.gov/otaq/fetrends.htm

and GHG standards for passenger cars issued in 2012 targeted an estimated fuel consumption reduction to 5.5L/100km by 2020 and 4.7L/100km by 2025[7].

The European Commission is responsible for proposing standards for passenger vehicles in Europe, with the European Parliament and Council voting on the final regulations. Mandatory targets for passenger cars were introduced in 2009, stipulating a target of 5.2L/100km by 2015 and 3.8L/100km by 2020. The European Commission has proposed a 2025 target of 3.5L/100km and a 2030 target of 2.9 L/100km[8].

To provide a closer look at the standard stringency among China, U.S. and EU, the fuel consumption targets and the annual reduction rates are shown in Table 1. Target values of the U.S. and EU standards are normalized to the New European Driving Cycle (NEDC) format (L/100km) as those in China[9]. Also, the actual type approval fleet-average fuel consumptions of China, the U.S. and the EU in 2010 and 2014 are listed in Table 2, together with their required annual reduction rates to meet the 2015 and 2020 targets.

Table 1. Comparison of fuel consumption targets (L/100km) under NEDC and required annual reduction rates

	2015 Target	2020 Target	2025 Target	2015 -2020 Annual rate	2020-2025 Annual rate
China	6.9	5.0	4.0	6.2%	4.4%
U.S.	6.8	5.4	4.2	4.5%	4.9%
EU	5.6	4.1	3.5	6%	3.1%

Table 2. Comparison of actual fuel consumptions (L/100km) under NEDC and required annual reduction rates

	2010 Actual	2014 Actual	2016 Actual	2010-2014 Annual Rate	2014-2015 Annual rate	2014-2020 Annual rate
China	7.8	7.2	6.9	2%	4.1%	5.9%
U.S.	7.3	6.9	6.6	1.4%	1.0%	3.2%
EU	6.2	5.3	5.0	3.8%	-	3.8%

Due to the low fuel consumption reduction rate (2%) from 2010 to 2014 in China, the required reduction rate to meet China's 2015 target is considerably high (4.1%). China eventually met the 2015 target in 2016 but, because of the delay, the annual reduction required to meet the 2020 target will be 5.9%.

The EU achieved its 2015 target in advance with a high reduction rate during the past four years (3.8%), and the US easily met its 2015 target with a required annual reduction

7 Hui He, Anup Bandivadekar, *Passenger car fuel-efficiency standards in China and the US: Stringency and technology, 2020–2025*, (ICCT: Washington DC, 2013). Retrieved from http://www.theicct.org/sites/default/files/publications/ICCT_PVfe-feasibility_201308.pdf

8 Jan Dornoff, Joshua Miller, Peter Mock, Uwe Tietge. *The European Commission regulatory proposal for post-2020 CO2 targets for cars and vans,* (ICCT: Washington DC, 2018). Retrieved from https://www.theicct.org/publications/ec-proposal-post-2020-co2-targets-briefing-20180109

9 Jörg Kühlwein, John German, Anup Bandivadekar. Development of test cycle conversion factors among worldwide light-duty vehicle CO_2 emission standards. (ICCT: Washington DC, 2014). Retrieved from https://www.theicct.org/publications/development-test-cycle-conversion-factors-among-worldwide-light-duty-vehicle-co2

rate of 1.0% from 2014. The fuel consumption reduction rate required to meet the 2020 standards in the U.S. and the EU are relatively lower than the requirement in China.

DATA SOURCES FOR ANALYSES

The analyses for Chinese passenger cars are based on a customized database provided by Segment Y for the China Passenger Car Baseline Project and additional data available from the China Automotive Technology and Research Center (CATARC). Data for the U.S. comes from 2015 Fuel Economy Trends Report by the EPA and data for EU is from an ICCT internal database[10]. In this paper, the technology deployments of passenger cars are compared among car fleets, segments and manufacturers. Table 3 shows a summary of the target parameters and technologies.

Table 3. Target parameters and technologies analyzed in this study

Parameter	Technology
Engine Displacement	VVT
Kerb Weight	Fuel Injection Type (GDI)
Horse Power	Turbo
Footprint	Hybrid powertrain
Power/ Weight Ratio	Diesel Engine
Fuel Consumption	CVT/6+ Transmission Gears
	Automatic Transmission

FLEET LEVEL COMPARISON BETWEEN CHINA, THE U.S., AND THE EU

In terms of fleet characteristics, shown in Figure 2, passenger cars in China shared more in common with the European passenger cars than those in the U.S. in terms of engine displacement, curb weight, footprint, and horsepower. While the increasing average curb weight and footprint in China were relatively high compared with those in the U.S. and the EU, its reduction rate of average fuel consumption fell behind the other two markets from 2010 to 2014.

U.S. passenger car fleet. Despite having the largest average values of engine displacement, curb weight, horsepower, footprint and power/weight ratio in 2010 and 2014, the average fuel consumption of the U.S. passenger car fleet was still 9.6% lower than the Chinese fleet in 2014. This indicates a big gap of fuel-efficiency technology deployments between these two markets.

EU passenger car fleet. The EU fleet showed the highest decreasing rate of fuel consumption at 4% annually, but lowest increasing rate of horsepower at 1.8% annually from 2010 to 2014. The average power-to-weight ratio of the EU passenger car fleet was the lowest in 2010 and 2014, arguably reflecting a trade-off between performance and fuel efficiency.

10 Peter Mock, *European vehicle market statistics – Pocketbook 2015/16* (ICCT: Washington DC, 2015). Retrieved from: http://www.theicct.org/european-vehicle-marketstatistics-2015-2016

China passenger car fleet. The Chinese car market shifted to larger and heavier vehicles from 2010 to 2014 resulting in the highest increasing rates of curb weight at 1.6% annually and footprint at 2% annually. Although the average values of other characteristics, such as engine displacement, horsepower and power-to-weight ratio, were between those of the U.S. and EU passenger car fleets, the fuel efficiency of the Chinese fleet fell behind the other two markets in 2010 and 2014.

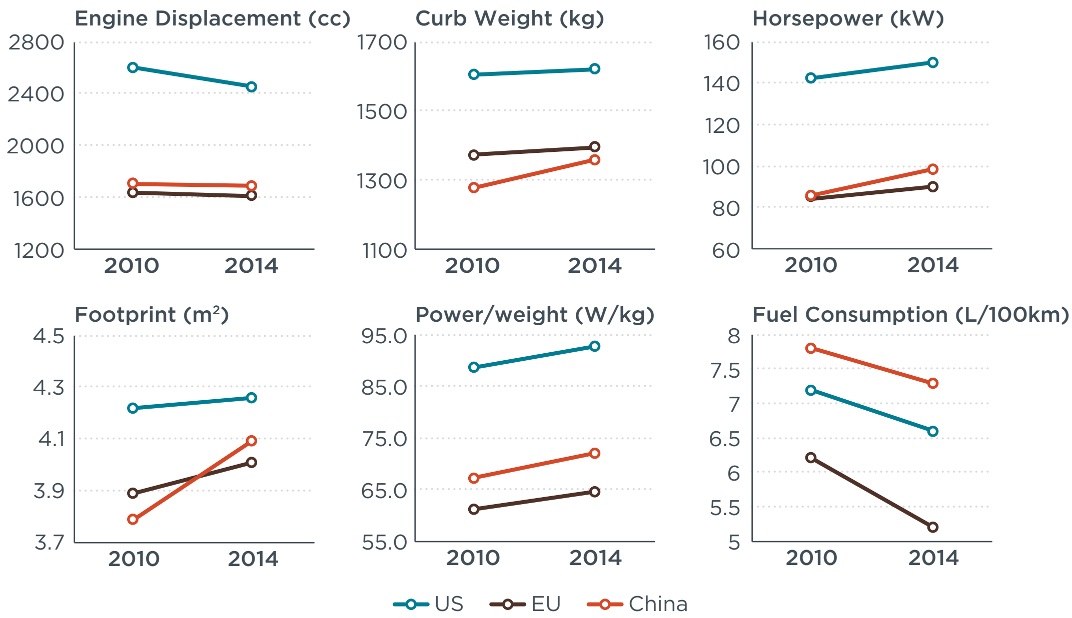


Figure 2. Fleet characteristics in China, U.S. and EU passenger cars between 2010 and 2014

As for fleet technology deployment (Figure 3), the U.S. passenger car fleet had higher penetrations of variable valve timing (VVT), gasoline direct injection (GDI), and continuously variable transmission (CVT) with six or more gears, whereas the European car fleet had higher penetrations of diesel engines and turbocharging. The technology adoption rates of VVT, GDI, Turbo, and CVT sharply increased for passenger cars in China and, by 2014, some technologies even had higher penetrations than in the U.S., and EU. For example, the VVT penetration in China passenger car fleet was 8 percentage points higher than that of Europe, and the turbo adoption rate was three percentage points higher than that of the United States. In addition to the deployment of fuel efficiency technologies on conventional cars, these three markets also recorded a steady rise of electric cars during the past few years. The U.S. passenger car fleet had the highest increasing rate of electric cars at 0.3% annually, followed by China and Europe, both at 0.2% annually. Most growth of electric cars uptake in China happened after 2014. The market penetration of electric vehicles increased from 0.3% in 2014 to 1.4% in 2016.

Although all regions had seen rapid growth in GDI and gasoline turbocharging, the U.S. had the highest GDI but lowest turbocharging deployment, suggesting that the U.S. had many naturally aspirated engines with GDI, while European manufacturers were primarily matching GDI with turbocharged engines. The latter is usually associated with a reduction of cylinder capacity. Downsized engines became more popular in Europe than in the U.S. and China.

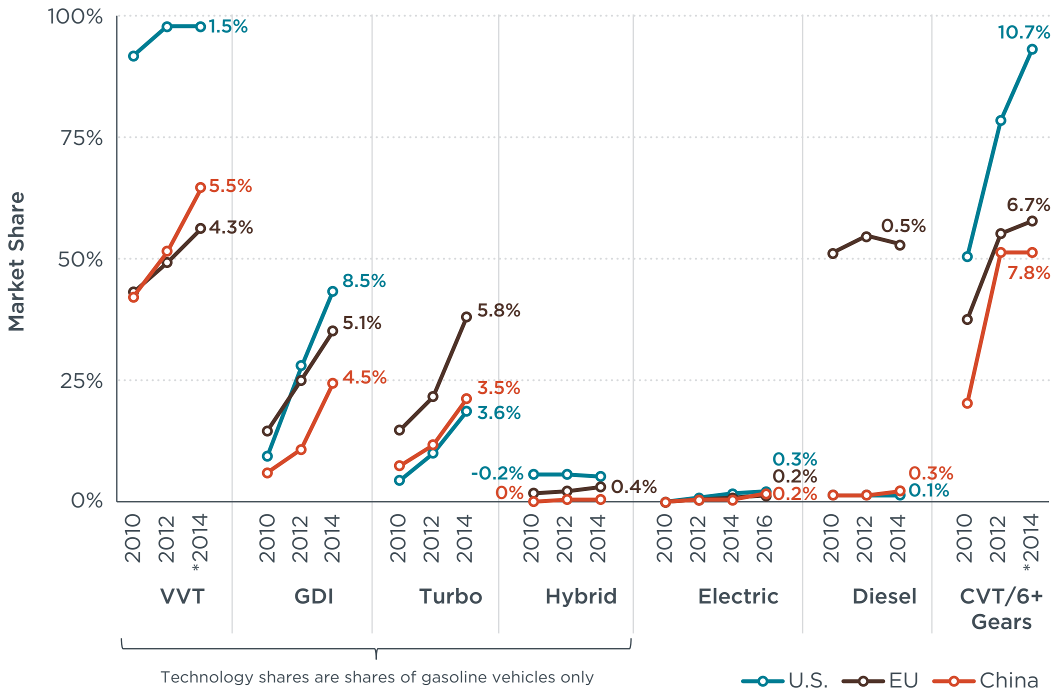


Figure 3. Powertrain technology adoption rates in China, U.S. and EU passenger cars from 2010 to 2014. The values represent average annual technology growth rates (*EU figures up to 2013 for VVT and CVT/6+).

SEGMENT-LEVEL COMPARISON BETWEEN CHINA, THE U.S., AND THE EU

The U.S. applies different vehicle classifications than the ones commonly used in Europe and China. As a result, for example, the Volkswagen Golf and similar vehicles are classified as small cars in the U.S., while they are lower-medium cars in Europe and China.

For this assessment, the China, U.S. and EU segments are matched based on similar characteristics, as shown in Table 4. When comparing average mass and footprint, the U.S. small-car segment is best comparable to the EU lower-medium segment, and lower medium is best compared to the medium segment in China (group 2). Similarly, U.S. midsize cars are matched with EU medium cars and Chinese upper medium cars (group 3), large U.S. cars with upper-medium cars in the EU and large cars in China (group 4), and EU off-road vehicles with U.S. and China SUVs (group 5). For the small-car segment in the EU and China, there is no direct equivalent in the U.S (group 1).

A segment with a market share of less than 3%, such as the upper-medium segment and large segment in China, is considered as a minor segment in this study. Although the medium segment was one of the major segments, taking up 18% of the Chinese passenger car market in 2014, its relatively low average mass (1417 kg) and footprint (4.2 m^2) could not match those of the U.S. midsize segment or the EU medium segment. Thus, this analysis categorizes the lower medium segment and medium segment in group 2 as a whole for comparison purpose.

Table 4. Comparison of characteristics by segment among China, U.S. and EU in 2014

Table 4. Comparison of characteristics by segment among China, U.S. and EU in 2014

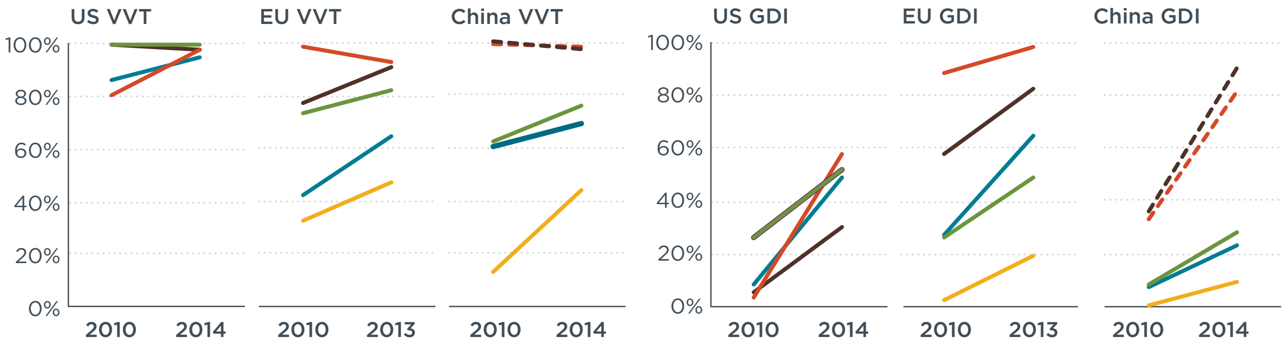
Group	Region	Segment	Market Share	Curb Weight (kg)	Footprint (m^2)	Enigine Displacement (cc)	Horsepower (kw)	Power/ Weight (w/kg)	Fuel Consumption (L/100km)
1	China	Small	6%	1069	3.6	1385	73	68	6.1
	US	-	-	-	-	-	-	-	-
	EU	Small	28%	1171	3.7	1294	65	56	4.8
2	China	Lower Medium-Medium	51%	1297	4.1	1636	93	72	6.8
	US	Small	31%	1487	4	2261	144	97	6.6
	EU	Lower Medium	34%	1391	4.1	1572	90	65	4.7
3	China	Upper Medium	2%	1596	4.4	1973	137	86	7.4
	US	Midsize	38%	1601	4.3	2393	142	89	6.4
	EU	Medium	17%	1624	4.4	1988	118	73	5.0
4	China	Large	1%	1718	4.5	2371	149	87	9.5
	US	Large	4%	1722	4.5	2966	185	107	7.9
	EU	Upper Medium	4%	1849	4.6	2380	156	84	5.4
5	China	SUV	20%	1538	4.1	1898	114	74	8.1
	US	SUV	27%	1750	4.3	2573	155	89	8.0
	EU	Off-Road	4%	1585	4.2	1852	107	68	5.6

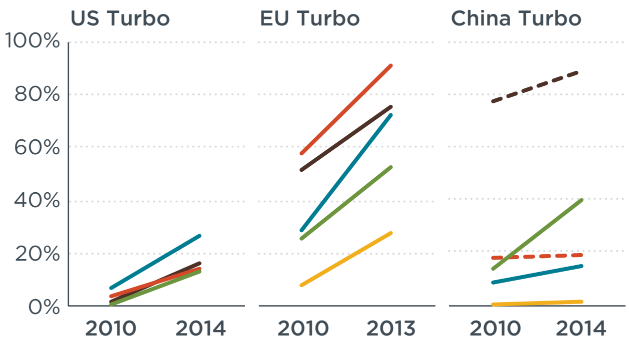
The technology adoption rates of Chinese group 3 and group 4 stood out in 2010 and 2014. However, the corresponding upper-medium segment and large segment took up only 2% and 1%, respectively, of the Chinese passenger car fleet. Thus, they could not truly represent mainstream technology deployment in China. Compared with clear technology distribution by segment in the EU and China, U.S. passenger cars had a relatively centralized and common deployment of technologies for all segments, as shown in Figure 4 and Figure 5. U.S. data from the past two decades shows that new technologies can be deployed to a large fraction of the fleet quickly, thanks to platform sharing and improved manufacturing flexibility in the modern auto industry[11].

Group 2 includes segments that contributed to more than 30% of market share in each country in 2014. The engine displacement of the small segment in the U.S. were 38% larger than that of lower medium-medium in China and 44% larger than lower medium in Europe. As a primary segment in China, lower medium-medium segment showed less adoptions of advanced engine technologies, except for VVT, which was adopted at a rate slightly above the EU.

SUVs in group 5 had become a popular segment for both U.S. and China by 2014, taking up 27% and 20% of the markets, respectively. However, the characteristics of SUVs in China, such as curb weight, engine displacement and horsepower. were much smaller than those in the U.S. In addition, adoption of advanced engine technology in Chinese SUVs fell behind those of the U.S. and the EU, except for turbocharging, which was 26% higher than the U.S. in 2014.

11 Nic Lutsey, N. (2012). "Regulatory and technology lead-time: The case of US automobile greenhouse gas emission standards," *Transport Policy*, 2012, 21: 179–190. Retrieved from http://dx.doi.org/10.1016/j.tranpol.2012.03.007

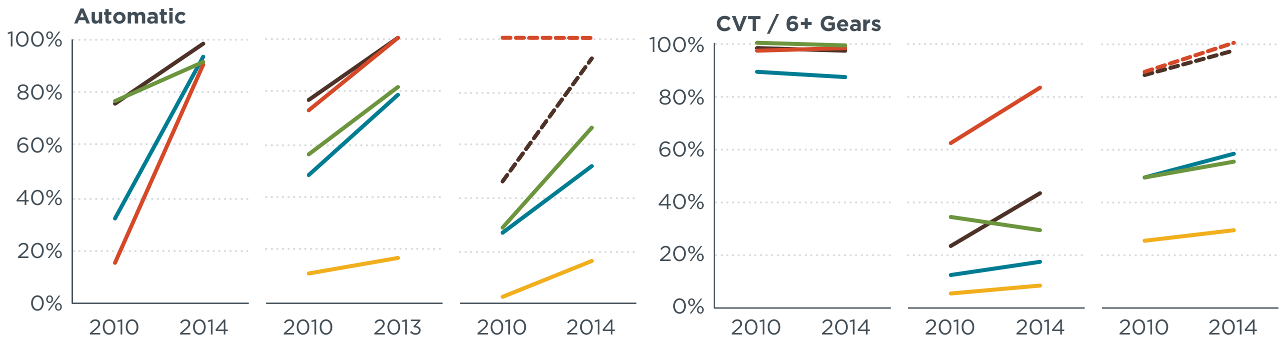




	Group #1	Group #2	Group #3	Group #4	Group #5
China	Small	Lower Medium-Medium	Upper Medium	Large	SUV
US	-	Small	Midsize	Large	SUV
EU	Small	Lower Medium	Medium	Upper Medium	Off-road

Figure 4. Engine technology adoption rates by segment for China, U.S. and EU passenger cars in 2010 and 2014 (segment with a market share less than 3% is marked by a dash line; EU figures up to 2013 for VVT).

The market share of automatic transmissions, including conventional automatic transmissions, CVTs, dual-clutch transmissions (DCTs), and automatic-manual transmissions (AMTs), increased in China across all segments. Most of the U.S. cars were traditionally equipped with automatic transmission, while those in Europe mainly adopted manual transmission. As for multi-gear technologies, there were significant improvements across three regions and all segments, except for small segments in China and Europe.



	Group #1	Group #2	Group #3	Group #4	Group #5
China	Small	Lower Medium-Medium	Upper Medium	Large	SUV
US	-	Small	Midsize	Large	SUV
EU	Small	Lower Medium	Medium	Upper Medium	Off-road

Figure 5. Transmission technology adoption rates by segment for China, U.S. and EU passenger cars in 2010 and 2014 (segment with a market share less than 3% is marked by a dash line; EU figures up to 2013 for CVT/6+ Gears).

MANUFACTURE LEVEL COMPARISON BETWEEN CHINA, THE U.S., AND THE EU

This analysis compares the technology deployment of some global brands that produce and sell vehicles in all three markets. To receive permission to produce vehicles in China, China authorities require foreign investors to pair with domestic independent automakers. This type of manufacturer is called a joint venture. One brand is able to pair with different independent automakers and form different joint ventures. This study focuses on six brand groups. All the brand groups listed in Table 5 launched at least one joint venture in China by 2014.

Under each brand group, manufacturers based in the U.S. produced the largest and heaviest cars with the highest power-to-weight ratio, while European manufacturers demonstrated the opposite. Manufacturers in China produced cars with the highest rate of fuel consumption compared with those in the U.S. and EU.

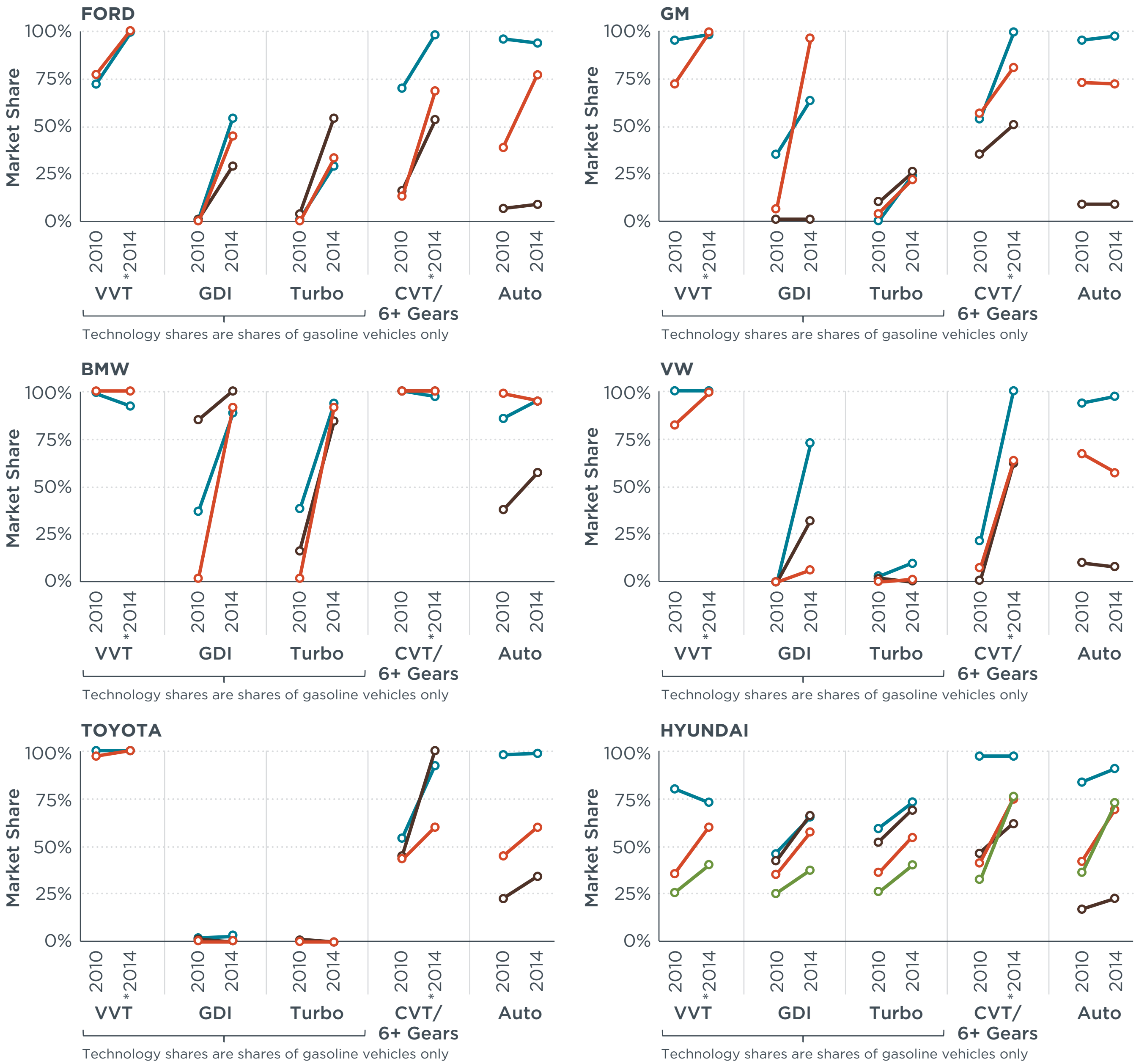
Table 5. Comparison of characteristics by manufacturer among China, the U.S. and the EU in 2014

Group	OEM	Region	Market Share	Engine Displacement (cc)	Curb Weight (kg)	Footprint (m^2)	Horse Power (kW)	Power/ weight (w/kg)	Fuel Consumption (L/100km)
FORD	**Ford**	US	10%	2362	1625	4.3	151	93	6.8
	Ford	EU	7%	1448	1358	4.0	83	61	5.0
	Chang'an-Ford	CHINA	4%	1674	1407	4.1	109	77	7.0
GM	**GM**	US	14%	2550	1696	4.3	159	94	7.1
	GM	EU	7%	1519	1444	4.0	85	59	5.4
	Shanghai-GM	CHINA	5%	1843	1529	4.3	112	73	7.8
TOYOTA	**Toyota**	US	16%	2340	1563	4.2	125	80	5.9
	Toyota	EU	7%	1577	1317	3.9	77	58	4.7
	FAW Toyota	CHINA	3%	1806	1308	4.1	100	76	6.7
VW	**VW**	US	6%	2181	1650	4.2	148	90	7.2
	VW	EU	25%	1665	1411	4	96	68	5.1
	FAW VW	CHINA	9%	1700	1426	4.2	104	73	7.1
	Shanghai VW	CHINA	9%	1602	1314	4	91	69	7.0
BMW	**BMW**	US	4%	2290	1749	4.4	191	109	6.8
	BMW	EU	6%	2057	1581	4.3	131	83	5.2
	BMW-Brilliance	CHINA	1%	2075	1672	4.7	146	87	7.4
HYUNDAI	**Hyundai**	US	13%	2124	1518	4.2	136	90	6.6
	Hyundai	EU	6%	1452	1311	4	78	59	5.3
	Beijing-Hyundai	CHINA	6%	1723	1294	4.1	100	77	7.2

Each brand group had developed a unique strategy of technology deployment in passenger cars in these regions, as is shown in Figure 6. For example, Ford focused on the adoptions of VVT, GDI, turbocharging and advance transmission, and showed obvious and balanced technology improvement in all regions. General Motors (GM) dramatically increased its GDI adoption for China Shanghai-GM by 90%, while little expansion of the technology was seen in Europe from 2010 to 2014.

BMW greatly improved the adoptions of GDI and turbocharging in all regions, especially for China BMW-Brilliance, both of which increased by 88%. In addition, almost every model of BMW was equipped with VVT and CVT/6+. VW showed balanced deployment of engine and transmission technologies across all markets, except in China, where adoption rates of CVT/6+ for FAW VW and Shanghai VW increased by 33% and 43% respectively.

Toyota vigorously promoted multi-gear transmission in all regions, and VVT was applied to nearly every model of Toyota by 2014 with little deployment of GDI or turbocharging. Hyundai primarily developed GDI and multi-gear transmission across all markets, and VVT was applied to nearly every model of Hyundai with little focus on turbocharging by 2014. In addition, the 2% annual GDI growth rate in Beijing-Hyundai produced vehicles was relatively low compared with the 19% growth rate in the U.S. and 8% growth in EU. This indicates that GDI had become a mature technology for Hyundai outside of Chinese markets.



	FORD	GM	BMW	VW	TOYOTA	HYUNDAI
China Manufacturer A	Chang'an-Ford	Shanghai-GM	BMW-Brilliance	FAW VW	FAW Toyota	Beijing-Hyundai
China Manufacturer B	-	-	-	Shanghai VW	-	-

Figure 6. Engine and transmission technology adoption rates by manufacturer for China, U.S. and EU passenger cars in 2010 and 2014 (*EU figures up to 2013 for CVT/6+; VVT by EU manufacturers and turbo by U.S. Toyota not available from 2010 to 2014)

CONCLUSIONS

A key objective of this paper was to compare fuel efficiency technology deployment of passenger cars in China, Europe and the United States. All regions showed rapid technology diffusions in target years, which indicates the development was a response by vehicle manufacturers to the increasingly stringent fuel consumption standards. However, there were differences in the mix of technologies:

- In terms of fleet characteristics, passenger cars in China still shared more in common with the European passenger cars. Passenger cars in in the U.S. still have the largest engine displacement, curb weight, footprint, and horsepower. While the increasing rates of average curb weight and footprint in China were relatively high compared with those in the U.S. and EU, its reduction rate of average fuel consumption fell behind the other two markets from 2010 to 2014.
- The U.S. passenger car fleet had a faster uptake of VVT, GDI, and CVT or transmission with six or more gears, whereas there was higher penetration of diesel engines and turbocharging in Europe. The technology adoption rates of VVT, GDI, turbo, and advance transmissions sharply increased for passenger cars in China from 2010 to 2014. China is also catching up on the uptake of electric vehicles after 2014.
- As a primary segment in China, the lower medium to medium segment showed less adoptions of advanced engine technologies, except for VVT, which had an adoption rate slightly above the EU. SUVs had become a popular segment for consumers in the U.S. and China by 2014. However, the characteristics of SUVs in China were much smaller than those in the U.S., such as curb weight, engine displacement and horsepower. In addition, advanced engine technology adoptions in Chinese SUVs fell behind those of the U.S. and the EU, except for turbocharging, which was 26% higher than the U.S. in 2014.
- Under each brand group, manufacturers based in the U.S. produced the largest and heaviest cars with the highest power-to-weight ratio, while European manufacturers demonstrated the opposite. In addition, each group had developed a unique strategy of technology deployment in passenger cars for each region. For example, GM dramatically increased its GDI adoption for China Shanghai-GM by 90%, while the technology hardly spread in Europe from 2010 to 2014. Hyundai had much higher growth rates of GDI adoption in the U.S. (19%) and the EU (8%) than in China (2%), indicating that Hyundai deployed more GDI applications outside China.

This briefing comparing the technology evolution between 2010 and 2014 provides a reference for upcoming work which evaluates the technology pathway and cost to achieve long term (2025-2030) fuel efficiency standards. Based on the analysis, we make the following recommendations for next steps:

- Although not entirely synchronized, fuel-efficiency technology development in passenger cars share similar trends in China, the EU, and the United States. Thus, the simulation model developed by Europe and the United States should be applied for future assessment of potential effects of advanced technologies on LDV fuel use in China. Adjustment are needed to customize the evaluation to the Chinese market.
- The baselines of fuel efficiency technologies in 2014 in China have been greatly improved from the 2010 level. It is necessary to redefine the baseline vehicle in each segment for future evaluation.

» Certain technology gaps still exist when comparing passenger cars in China with those in Europe and the United States. Thus, the configuration of the baseline vehicle in Europe and the United States should be adjusted.

» Since the distributions of vehicle segments in China have changed over years, the evaluation should take account of the representativeness of each segment in the future fleet.

» This analysis excludes some important fuel efficiency technologies, such as stop-start, due to lack of data. For future studies, it would be desirable to obtain data for technologies not included in this paper to extend the analysis to a broader range.