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THE EVOLUTION OF COMMERCIAL VEHICLES IN CHINA: A RETROSPECTIVE EVALUATION OF FUEL CONSUMPTION STANDARDS AND RECOMMENDATIONS FOR THE FUTURE

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EXECUTIVE SUMMARY

Although China is currently developing the fourth stage of its fuel consumption standards for heavy-duty vehicles (HDVs), an independent, ex-post assessment of the previous stages does not exist. By providing a quantitative appraisal of the effect achieved by previous stages of the standards, this study closes that knowledge gap.

We analyzed data from 10.5 million trucks and buses in the period 2012 to 2017, covering the first two stages of the fuel consumption standards. Our analysis finds that Stage 1 and Stage 2 standards had only a limited impact on the certified fuel consumption of trucks and buses in China. After Stage 2 was introduced, some HDV segments exhibited only a slight downward trend in fuel consumption, and others even a slight upward trend.

We also find that Stage 3 standards, first implemented for new type approvals in 2019, are not expected to deliver benefits on the same order of magnitude as the tightening of the limits would suggest. Because a significant portion of the vehicles certified to Stage 2 were already compliant with Stage 3, the actual improvement in certified fuel consumption across the fleet will likely be less. Further, an improvement in certified fuel consumption does not necessarily result in better real-world performance, due to flexibilities provided by the certification procedure.

Based on our findings, we offer the following policy recommendations for the development of Stage 4 standards and the fuel consumption certification methodology used:

1. Stage 4 standards present an opportunity to set a technology-forcing regulation that would exploit all cost-effective technologies. A stringent Stage 4 standard can force new technologies into the market and improve the competitiveness of Chinese manufacturers in international markets.
2. Certification drive cycles that are representative of real-world operation are fundamental for driving fuel-saving technologies to the market. Including road grade would improve for the real-world representativeness of the certification process and incentivize important fuel-saving technologies that thrive on mountainous topographies.
3. Aerodynamic, tire rolling resistance, and lightweighting technologies are essential for improving the fuel consumption of trucks and buses, and could be incentivized better in Stage 4.
4. China's fuel consumption certification could benefit from shifting from chassis dynamometer testing toward vehicle simulation.
5. The harmonization of component testing with international standards can decrease the compliance and certification costs of Chinese manufacturers with a global footprint.

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INTRODUCTION

The commercial vehicle manufacturing industry boomed in China in recent decades, and this was especially pronounced in the heavy truck segments. China has also become the largest heavy-duty vehicle (HDV) market in the world (Sharpe & Muncrief, 2015) and has produced about 1 million vehicles per year since 2010 (J. Li, 2016).

At the same time, in an effort to increase the international competitiveness of domestic HDV manufacturers and reduce the carbon dioxide (CO_2) emissions from its growing fleet, China introduced fuel consumption standards for HDVs in three separate stages, each with increasing stringency.[1] The most recent was Stage 3, which was implemented in 2019 for new type approvals. However, to date there exists no independent retrospective assessment of the impact of Stage 1 and Stage 2, including whether they spurred any reduction in the fuel consumption of HDVs. This study aims to fill that knowledge gap and use the results to provide fact-based policy recommendations for future Stage 4 standards, which are currently under development and might not be implemented until 2025.

We analyzed the fuel consumption of internal combustion HDVs produced from 2012 to 2017, which were certified under Stage 1 and Stage 2 fuel consumption standards. Battery and fuel cell electric vehicles are not within the scope of this study.

This paper is structured as follows. Section 2 provides the policy background and details recent developments in China's HDV market. Section 3 describes the methodology used to analyze the evolution of key technical characteristics of selected HDV segments and their certified fuel consumption during 2012–2017. These results are then presented in Sections 4 and 5. Section 6 analyzes the gap between the certified fuel consumption—used to comply with the fuel consumption standards—and the expected fuel consumption under more representative testing procedures. Section 7 summarizes the key findings and presents policy recommendations for the Stage 4 standards.

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[1] Regulations QC/T 924-2011, GB 30510-2014, and GB 30510-2018 are also known as Stage 1, 2, and 3 respectively.

POLICY BACKGROUND

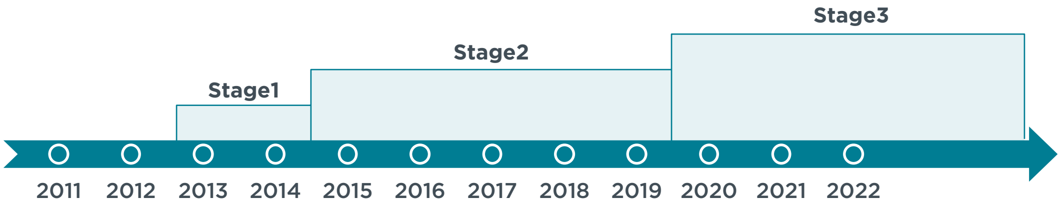
Stage 1 was an industry standard proposed by the responsible ministry, the Ministry of Industry and Information Technology (MIIT), specifically for the HDV industry. It was implemented in mid-2012 for type approval of new models, and in mid-2014 for all new sales. Three popular types of HDVs—tractor-trailers, straight trucks, and coaches—were regulated under Stage 1. Stage 2, which was the first-ever national standard proposed by the State Council of China, was implemented in mid-2014 for type approval of new models, and in mid-2015 for all new sales. The switch from an industry standard to a national standard, the latter led by the State Council of China instead of MIIT, reflects that there was interest in reducing HDV fuel consumption at the top level of China's government.

Stage 2 incorporated two new regulated segments, city buses and dump trucks, and tightened the fuel consumption limits for tractor-trailers, straight trucks, and coaches by 10.5%–14% compared to the limits under Stage 1. The Stage 3 standards maintained the same scope as Stage 2 in terms of regulated segments, but further tightened the fuel consumption limits by about 15%. The Stage 3 standards entered into force in July 2019 for new type approvals and will take effect in July 2021 for all new vehicles.

Figure 1 provides a summary of the implementation timeline and main elements of China's HDV fuel consumption standards. Below that, Figure 2 illustrates the cumulative improvement by Stage 2 (brown) and Stage 3 (blue) over Stage 1 for different vehicle segments. As dump trucks and city buses were first regulated by Stage 2, only the improvement by Stage 3 is available those two segments.

GB 30510-2014 Stage 2 was implemented.
- First-ever national standard on HDV fuel consumption.
- Increased stringency by 10.5% – 14.5% for each segment.
- Expanded to 5 segments, including dump truck and city bus.

GB 30510-2018 Stage 3 was implemented.
- Even more strict than Stage 2 by 10.7% – 17.9%.
- Approaching advanced standards around the world.



Industry specific-standard QC/T 924-2011 (Stage 1) was implemented.
- First-ever Chinese HDV fuel consumption standard.
- Only 3 segments of HDV are included, i.e., truck, coach, tractor trailer.

Figure 1. Timeline of the evolution of Chinese HDV fuel consumption standards

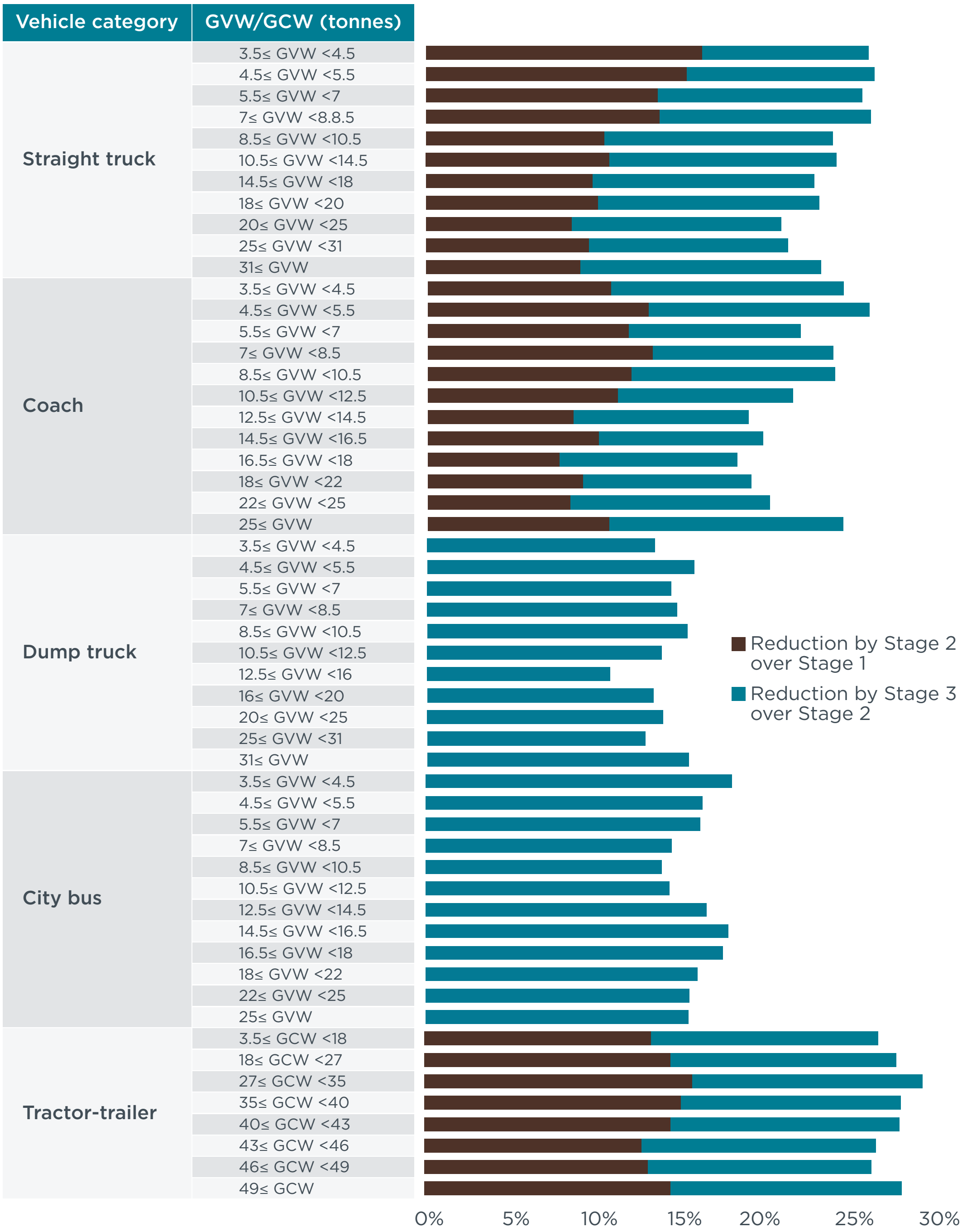


Figure 2. Fuel consumption improvement mandated by Stage 2 and Stage 3 over Stage 1 for vehicle categories (except for dump trucks and city buses, which were first covered by Stage 2). GVW: Gross vehicle weight. GCW: Gross combination weight.

STAGE 1 – QC/T 924-2011

The Stage 1 standards were officially published by the end of 2011. They took effect on July 1, 2012 for new type approvals and on July 1, 2014 for all new vehicle sales. The standards covered the three largest HDV segments in China at that time—straight trucks, coaches (excluding city buses), and tractor-trailers—and these were further subdivided by gross vehicle weight (GVW), in order to set pertinent not-to-exceed fuel consumption limits.

The Stage 1 limits are set as a function of GVW following a stair-like shape, as shown in Figure 3. While straight trucks and coaches share a similar fuel consumption limit when the GVW is below 5 tonnes, the limits for straight trucks increase faster than those for coaches as the GVW increases. Additionally, the limits for straight trucks and coaches plateau at 50 L/100 km and 33 L/100 km, respectively. The Stage 1 limits for tractor-trailers, meanwhile, start at 38 L/100 km for vehicles with a GCW below 18 tonnes and go up to 56 L/100 km for the heaviest tractor-trailers, which are 49 tonnes GCW.[2]

The certified fuel consumption of new vehicle sales during 2013–2014, when Stage 1 was in-force, is also shown in Figure 3. The data suggests that manufacturers faced almost no issues complying with Stage 1 standards, as most certified values were far below the limits set by the regulation.

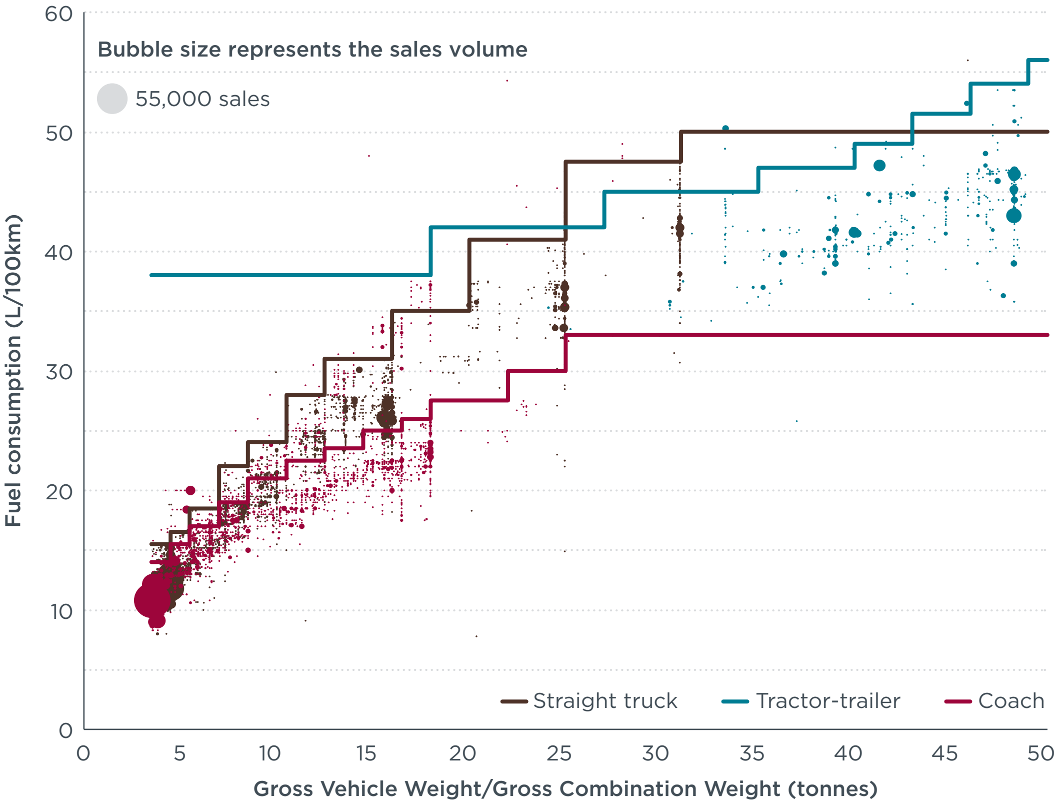


Figure 3. Fuel consumption limitations of the China HDV Stage 1 standard and the corresponding performance of new vehicle sales for each regulated segment during 2013–2014. Bubble size reflects the number of sales for each model.

STAGE 2 – GB 30510-2014

Stage 2, the first-ever nationwide standard, was published in February 2014. It went into effect on July 1, 2014 for new type-approvals and on July 1, 2015 for all new sales. Dump trucks and city buses were added as regulated segments. To set the Stage 2 fuel consumption limits, more than 900 vehicles were tested, and this was a substantial increase from the 314 vehicles that had been tested for Stage 1. Stage 2 became a regulatory landmark in China's attempt to curb the fuel consumption of HDVs.

Compared to Stage 1, Stage 2 mandated improvements between 10% and 19% for straight trucks, between 15% and 16% for tractor-trailers, and between 11% and 12% for coaches. Detailed Stage 2 fuel consumption limits for each segment are shown in Figure 4. The figure also shows the certified fuel consumption of new vehicles during 2015–2017, when Stage 2 standards were in force. Stage 2 limits did not result in significant fuel consumption improvement within the three main vehicle segments—tractor trailers, straight trucks, and coaches. The not-to-exceed fuel consumption

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[2] Gross combination weight captures the maximum total weight of a combination of a tractor unit and a trailer.

limits do get closer to the certified values. However, a large number of vehicles still significantly outperformed the Stage 2 limits. Therefore, the Stage 2 standards cannot be regarded as technology forcing, as manufacturers did not have to introduce any new technologies to comply. Technology-forcing standards not only drive the widespread commercialization of existing technologies, they require the development and deployment of additional ones.

Trends for each segment will be analyzed in more detail in Section 5.

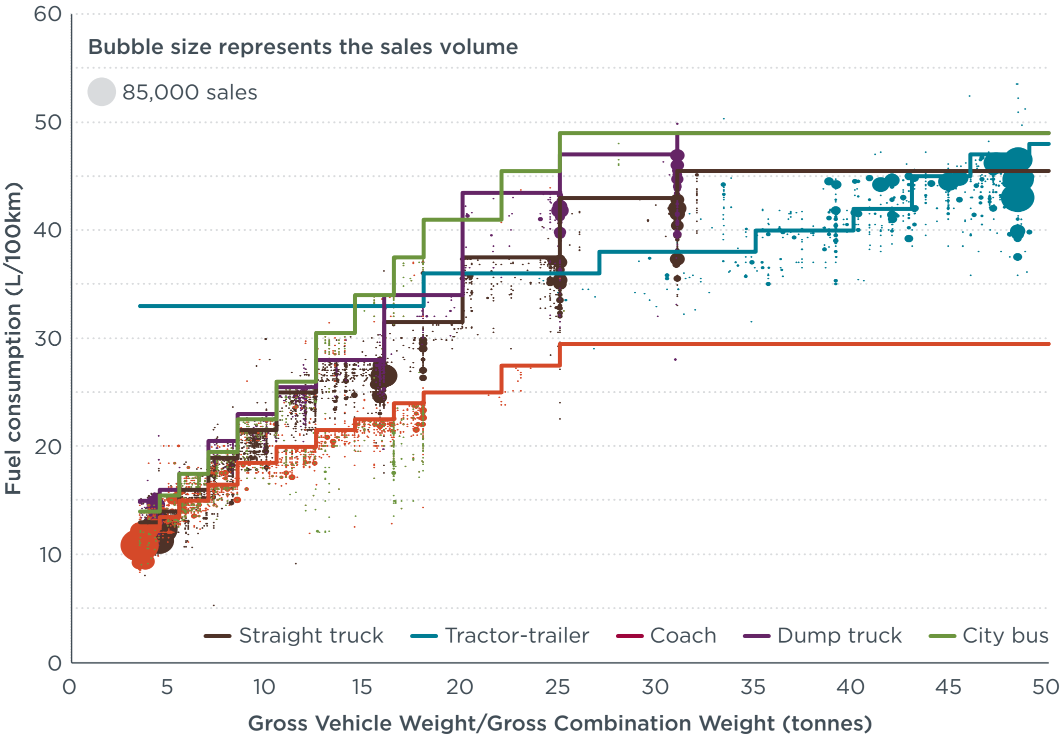

Figure 4. Fuel consumption limitations set by the China HDV Stage 2 standard and the corresponding performance of new vehicle sales for each regulated segment during 2015–2017. Bubble size reflects the number of sales for each model.

STAGE 3 – GB 30510-2018

This objective of Stage 3 was articulated in 2012 when China's State Council published a national plan calling for catching up with the frontline of international standards on HDV fuel consumption by 2020 (State Council of People's Republic of China, 2012). The Stage 3 standards therefore took effect on July 1, 2019 for new type approvals, and will be fully phased in by July 1, 2021 for all new sales. This timeline echoes the China VI HDV pollutant emission standards, which went into effect in 2019 for new type approvals and in 2020 for all new vehicle sales (MEE, 2019a).

The Stage 3 standard covers the same segments as Stage 2, but the fuel consumption limits were tightened in the range of 10.7%–17.9%. Tractor-trailers and city buses are required to achieve more than 15% fuel consumption improvement, coaches must improve by about 11.8%, and for straight trucks and dump trucks, the limits are 13.8% and 14.1% more stringent, respectively, than Stage 2 (Delgado & Li, 2017). The detailed Stage 3 fuel consumption limits, as a function of vehicle weight, are shown in Figure 5. The dataset analyzed in this study does not include any vehicles certified to this standard.

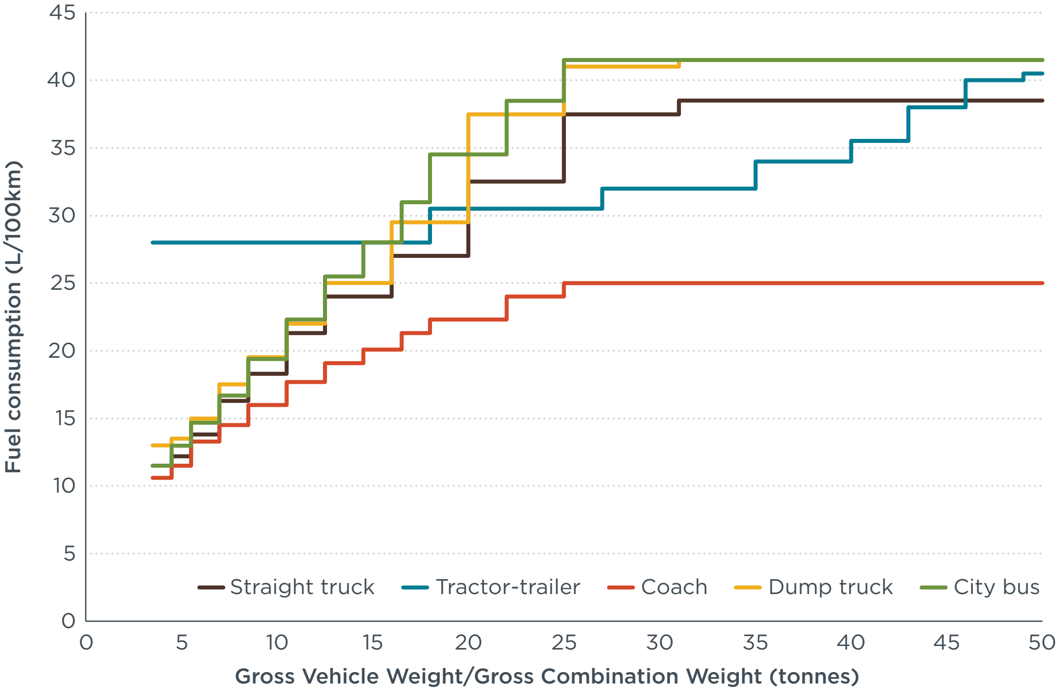

Figure 5. Fuel consumption limitations for each segment set by the China HDV Stage 3 standard.

HDV CERTIFICATION SYSTEM

The HDV certification system in China consists of three main stakeholders: regulatory authorities, technical support agencies, and original equipment manufacturers (OEMs). Figure 6 illustrates how these stakeholders work together.

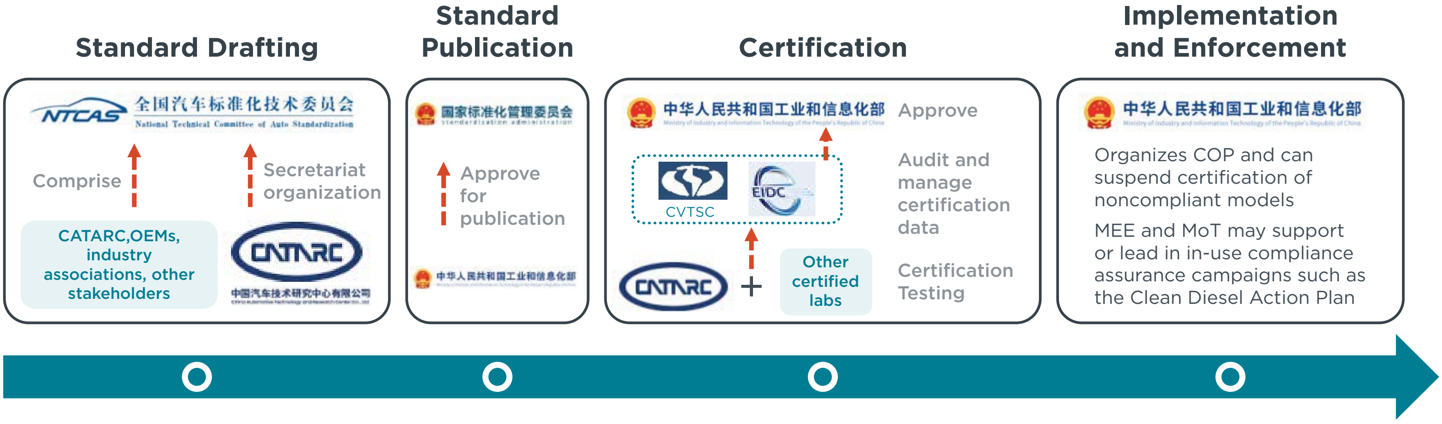

Figure 6. Overview of stakeholders in China's HDV certification system.

The primary regulatory bodies responsible for the HDV certification system and its management are the aforementioned MIIT, Ministry of Transport (MOT), Ministry of Ecology and Environment (MEE), and the Standardization Administration of China (SAC), the latter of which is the main publisher for certification. MIIT is responsible for fuel consumption certification and model type-approval, and MEE is responsible for emission certification. MOT is not involved in certification or approval, but plays a critical role in road transportation management after the OEM's models are approved and released on the market.

Technical support agencies, as the name suggests, are authorities related to model testing and they provide technical support to the regulatory authorities. China Automotive Technology and Research Center Co. Ltd. (CATARC) is the primary testing authority that provides consulting services to MIIT, which has responsibility for final model approval. Additionally, CATARC always plays the main role in drafting the text of the regulations. The National Technical Committee of Auto Standardization (NTCAS) and CATARC together form the secretariat organization for technical support in the development of fuel consumption standards.

Before a new model is allowed on the market, HDV manufacturers are required to conduct a series of mandatory tests specified by CATARC. Only after all tests are passed will the regulatory authorities grant approval for public sale. If all tests are not passed, the new model will not be permitted and will not be listed on the Approval & Announcement List, which is periodically updated by MIIT. The fuel consumption certification system for HDVs in China is illustrated in Figure 7.

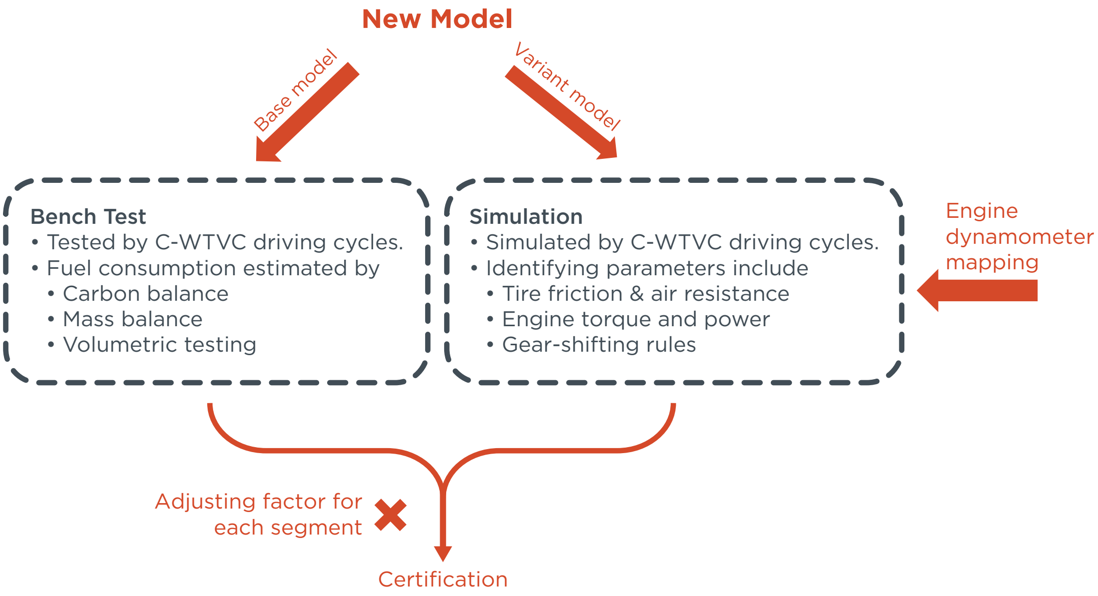

Figure 7. Flowchart of the HDV certification system in China.

Fuel consumption certification is divided into base model and variant model. Base models are a brand-new type of HDV model with a new configuration and structure. A model will be identified as a variant only if the GVW, frontal area, and engine power are less than that of the base vehicle.[3] Base models are to be tested on a chassis dynamometer over the C-WTVC driving cycle.[4] The fuel consumption of variant models can be certified either on a chassis dynamometer or by using a computer simulation model developed by CATARC.

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[3] This list is not exhaustive. For further information, see a related ICCT policy update (Muncrief, 2013)

[4] The C-WTVC is a slightly modified version of the World Harmonized Vehicle Cycle (WHVC) for the Chinese market. The WHVC was developed as part of Global Technical Regulation No. 4.

METHODOLOGY

The key data set for this study was purchased from CATARC and includes the information of nearly 18 million commercial vehicles on the road during the period from 2012 to 2017. Because we focus on HDVs—commercial vehicles of GVW above 3,500 kilograms—all other vehicle categories are excluded. The exclusion of those lighter vehicles, combined with a thorough data validation and cleaning, resulted in a total of 10.5 million vehicles being analyzed.

DEFINITION AND CLASSIFICATION OF HDVS IN THIS STUDY

The HDV fleet in China consists of mostly diesel-powered vehicles. Heavy-duty diesel vehicles were 73% of the total commercial vehicle population in 2018, according MEE's annual report (MEE, 2019b).

The current vehicle classification was defined by the national standard GB/T 15089-2001 (MIIT, 2001), in which China echoed the European classification system and grouped all motor vehicles into four categories: Category L (two- and three-wheelers), Category M (passenger vehicles), Category N (freight-vehicles) and Category O (trailers). This study only focuses on vehicles belonging to categories N and M.

Figure 8 presents an overview of the dataset analyzed in this study. China had HDV sales of 1.7 million in 2012 and almost 2 million in 2013; this dropped to 1.8 million and 1.3 million in 2014 and 2015, respectively. China's HDV market began to recover in 2016, and by 2017, total sales returned to the same level as 2013. The decline in HDV sales during 2014 and 2015 is a well-documented consequence of the broader economic turmoil during that period (Allen et al., 2015).

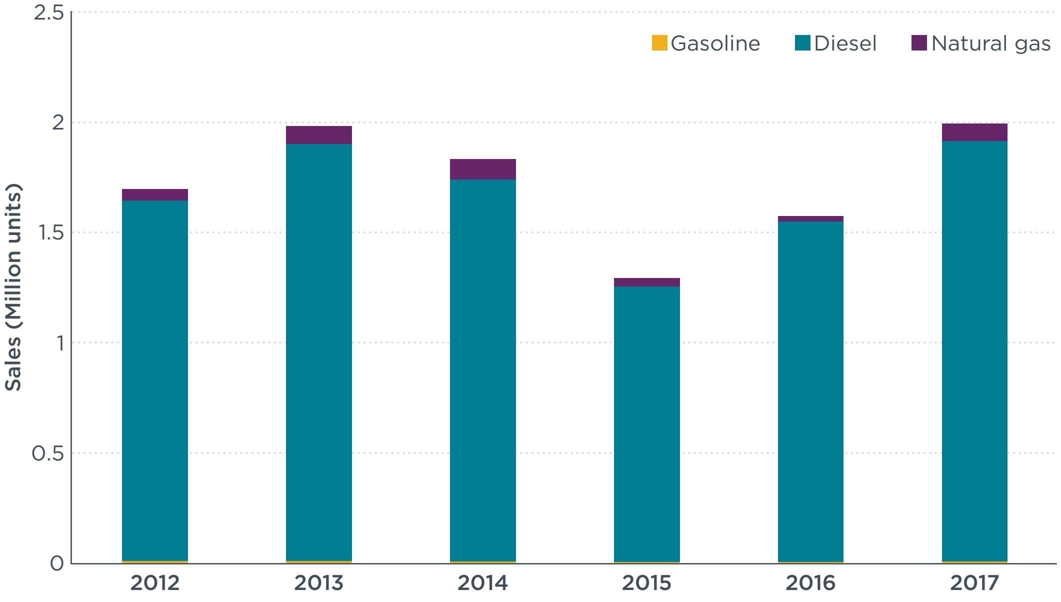

Figure 8. Sales by fuel type between 2012 and 2017 (electric HDVs are excluded).

Diesel engines dominated the conventional HDV market in China during the evaluation period, accounting for more than 95.3% of HDV sales. Still, natural gas powertrains have had a consistent market presence throughout the past years, peaking in 2014, when they represented 5.0% of new HDV sales. The penetration of gasoline powertrains in the HDV segments is negligible.

As shown in Figure 9, sales in the different vehicle segments were largely dominated by a few GVW ranges. Straight trucks were mostly concentrated at GVWs of around 5 tonnes, which exemplifies how important small straight trucks are within the regulatory category. Similarly, GVWs around 5 tonnes were also a large number of the sales of coaches and dump trucks. Most tractor-trailers were gathered around approximately GCW of 49 tonnes, which is the upper limit for the total weight of tractor-trailers in China (MIIT, 2016).

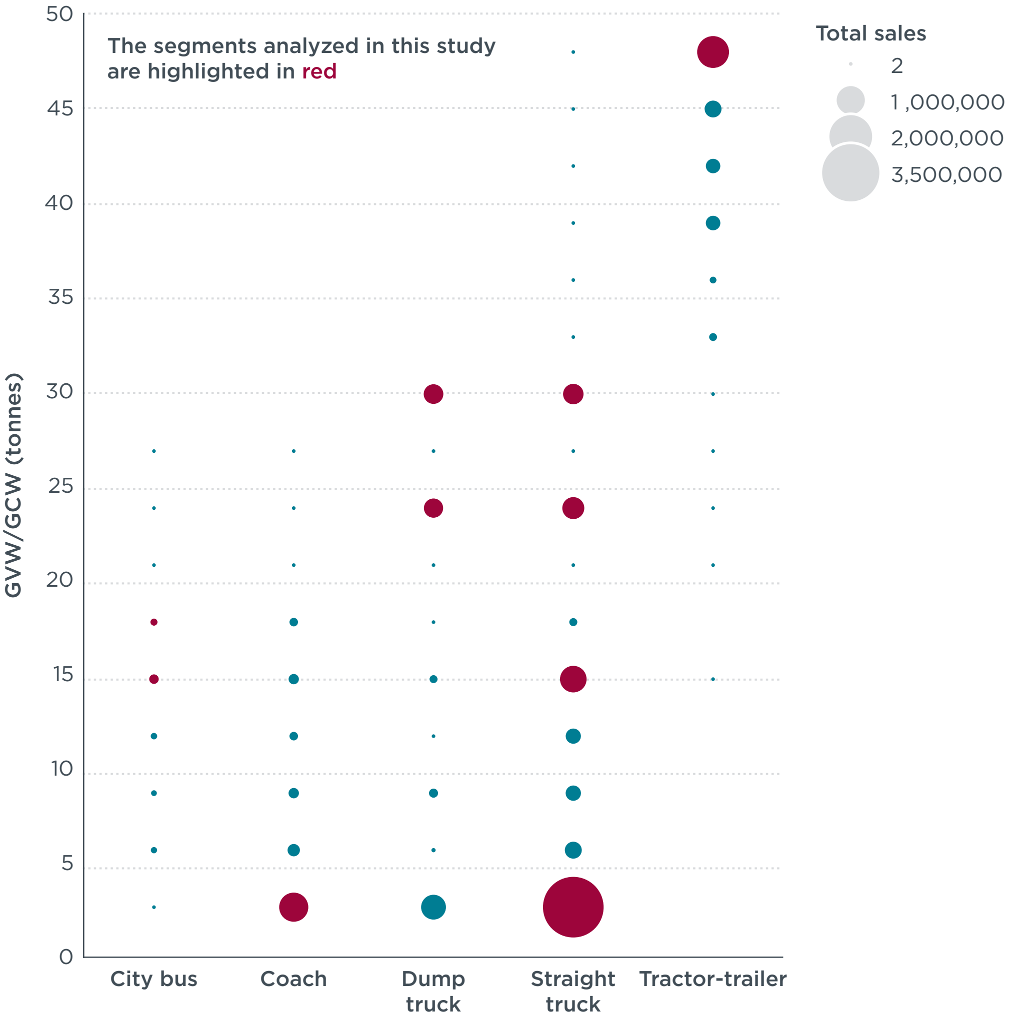

Figure 9. Mass distribution by vehicle category in the dataset. Red points are highlighted as segments analyzed in this study.

To limit the scope of the study and to allow for a deeper analysis of the most representative HDV types, only certain combinations of GVW ranges and vehicle segments were selected for further analysis. The selection is highlighted in blue in Figure 9 and summarized in Table 1.

Table 1. Segmentation applied in this study, which is narrower than the classifications in China's standards.

Vehicle category by Chinese standard[a]		Segmentation in this study[b]	No. of axles	GVW/GCW range (tonnes)
Truck (N)	Medium (N2)	Small straight truck	2	$3.5 < \text{GVW} \leq 4.5$
	Large (N3)	Medium dump truck	3	$20 < \text{GVW} \leq 25$
		Large dump truck	4	$25 < \text{GVW} \leq 31$
		Medium straight truck	2	$12.5 < \text{GVW} \leq 16$
		Large straight truck	4	$25 < \text{GVW} \leq 31$
		Tractor-trailer[c]	6	$46 < \text{GCW} \leq 49$
Bus (M)	Light (M2)	Coach	2	$3.5 < \text{GVW} \leq 4.5$
	Large (M3)	City bus	2 - 4	$14.5 < \text{GVW} \leq 18$

Table notes.

a: Classification of Power-driven Vehicles and Trailers by GB/T 15089-2001.

b: Fuel Consumption Limits by GB 30510-2018. HDV segments with GVW above 3,500 kg.

c: GCW is not available in CATARC's dataset. It is therefore estimated from an empirical formula provided by Wang and Zhang (2015), where the traction ratio (total weight/tare weight) of tractors in China generally range from 4.5 to 5.0.

DATA AVAILABILITY AND LIMITATION

Table 2 presents the rate of available fuel consumption data for each segment by year. In the early years of the evaluation period, fuel consumption data are scant. For example, only 2% to 3% of large straight trucks and medium dump trucks have fuel consumption data available in 2012 and 2013. Generally, the data availability of city buses is inferior to other segments throughout the whole period.

Table 2. Rate of available fuel consumption data in this study for each year and segment

	2012	2013	2014	2015	2016	2017
Medium dump truck	3%	8%	33%	69%	83%	96%
Medium straight truck	9%	23%	54%	74%	75%	69%
City bus	14%	24%	40%	57%	63%	59%
Coach	19%	43%	69%	84%	89%	88%
Large dump truck	5%	14%	43%	87%	95%	97%
Large straight truck	2%	10%	41%	84%	88%	86%
Small straight truck	9%	37%	71%	88%	92%	93%
Tractor-trailer	10%	21%	46%	82%	89%	85%

HDV MARKET IN CHINA 2012–2017

OVERVIEW

The market for HDVs in China during the study period was highly dynamic, not only because of the variability in sales of new HDVs, but also because of changes in vehicle segmentation and market shares among different manufacturers. Generally speaking, and with the exception of light coaches, most vehicle segments—as defined in Table 1—have witnessed significant growth since 2012. In 2015, however, several segments such as tractor-trailers, straight trucks, and dump trucks experienced a sharp decline of between 25% and 70% due to the economic downturn. Exports of buses and trucks shrunk by 11.8% and 24.6%, respectively, in 2015, compared to the previous year. Domestic demand for several segments also dropped notably, by 26.0% (large trucks) and 19.1% (medium trucks), in 2015 (National Bureau of Statistics of China, 2016).

Among all categories, and considering the complete 2012 to 2017 period, tractor-trailers exhibited the largest growth, with sales tripling and reaching nearly the same level as small straight trucks by 2017. Still, small straight trucks continued to be the largest segment in terms of sales volume. In 2017, 578,000 small straight trucks and 524,000 tractor-trailers were sold (see Figure 10).

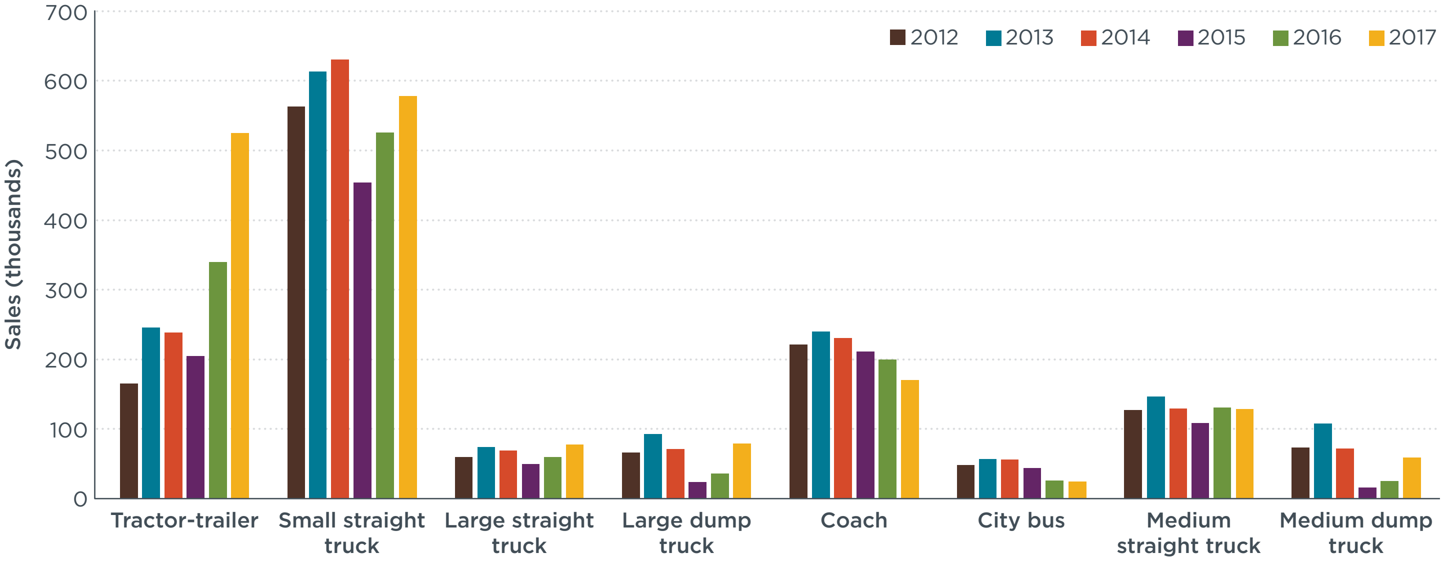

Figure 10. Total sales of each vehicle segment by year.

KEY MANUFACTURERS IN THE MARKET

In 2012, there were 670 HDV manufacturers in the market, with the top 8 manufacturers being responsible for 48% of total sales. In 2017, while the number of HDV manufacturers increased to 702, the dominance of the top 8 manufacturers grew as well, increasing to 51% that year.

Foton Motor sold the most units in 2012, but occupied third place in 2017. JAC Motors kept its second place in HDV market share from 2012 to 2017, with its sales increasing at the same pace as the overall market. FAW Group moved up from fourth place in 2012 to become the best-selling HDV manufacturer in 2017, with 300% growth during the study period. Figure 11 shows the top 8 manufacturers in 2012 and 2017, and the vehicle categories that represented the bulk of their sales. Although straight trucks were still the dominant category for most of the top 8 manufacturers in 2017, the share of tractor-trailers in their product portfolios increased substantially compared to 2012.

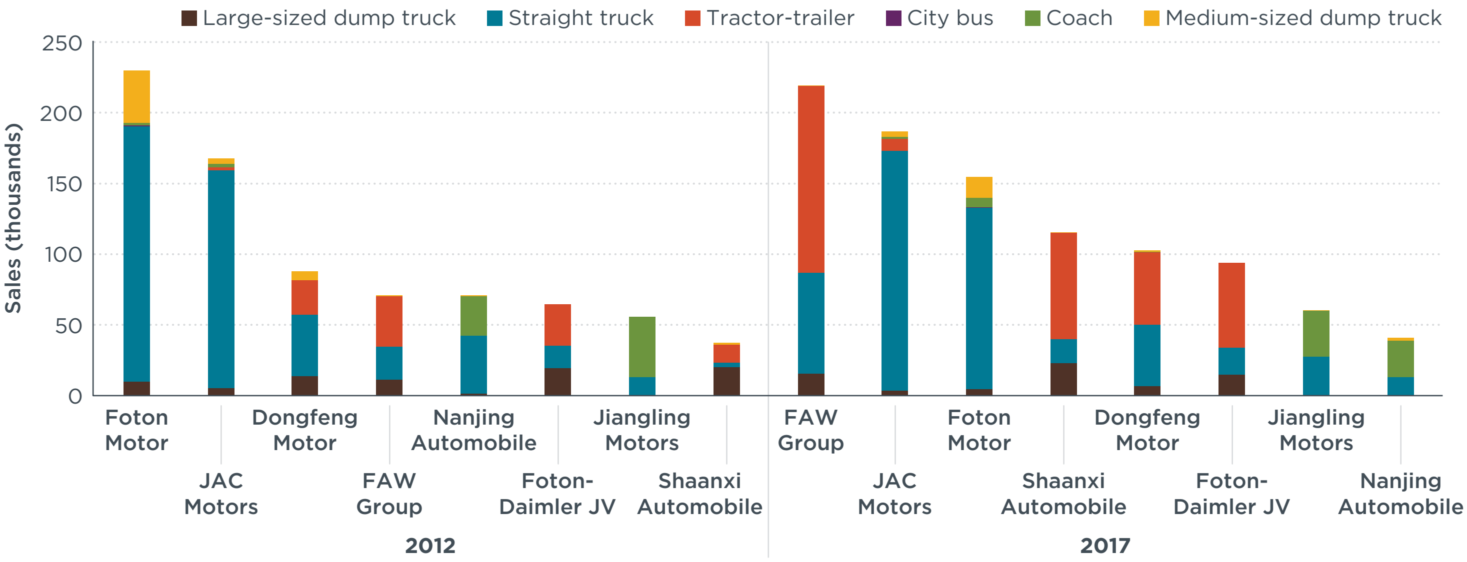

Figure 11. Key manufacturers and sales in 2012 and 2017.

TECHNICAL SPECIFICATIONS

Engine displacement and power

Engine displacement and engine power trends are shown in Figure 12. Tractor-trailers, large dump trucks, and large straight trucks all saw noticeable increases in engine displacement and power from 2012 to 2017, with engines gaining approximately 1 liter (10.0%–11.3%) of engine displacement and 40 kW (16.2%–18.5%) of power. On the other hand, the engine displacement of the remaining categories evaluated in this study stayed relatively constant, with coaches even exhibiting a reduction. Still, given the increase in power density—that is, the power output per unit of engine displacement—the decline in engine size did not impact the power output.

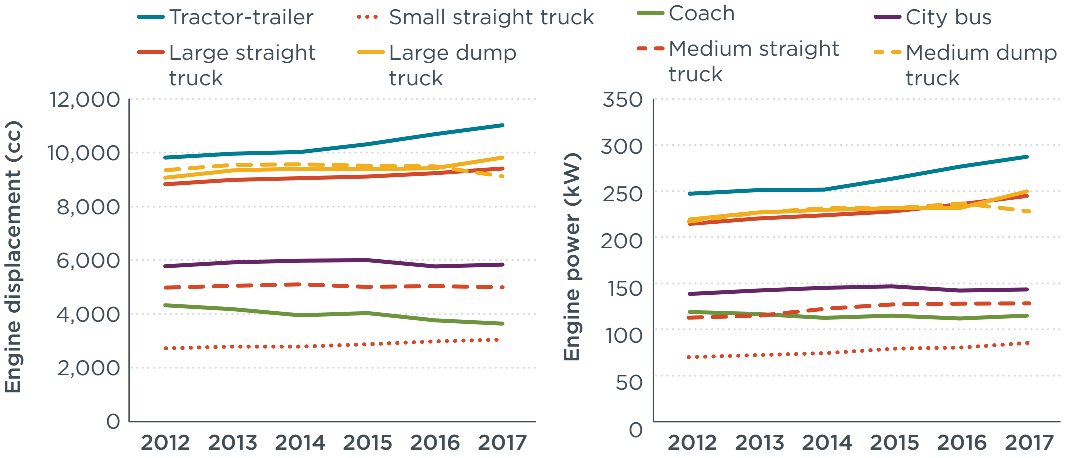

Figure 12. Average engine displacement (left) and average engine power (right) for each category by year.

Curb weight

Curb weight measures the total mass of the vehicle without any payload, but with standard equipment and necessary operating devices. Generally speaking, most vehicle segments became heavier in the evaluation period, with average growth of 5%–10% by 2017 compared to 2012. Coaches, however, declined from an average of 5,540 kg to 4,461 kg at the end of the period (Figure 13), and this change could reflect the structural changes of intercity transport in China. Railway is becoming more popular in the intercity transport market as a result of the growing coverage of China's CRH high-speed train system. Further, more people are driving their own cars instead of taking coaches. Thus, the market for large-size coaches for long distance transport is shrinking and this is expected to continue. This trend in coach size has also been reflected in statistics from the Ministry of Transport and reported by other outlets (Tang, 2019).

Large straight trucks exhibited the largest increase in average curb weight among all analyzed vehicle categories, after a sharp increase in 2017 of nearly 1,500 kg. Medium straight trucks also saw a gradual increase from 6,200 kg to 7,400 kg during the evaluation period. It should be noted that only the curb weight of the tractor-truck is reported in Figure 13; the curb weight of the trailer for tractor-trailer combinations is not included.

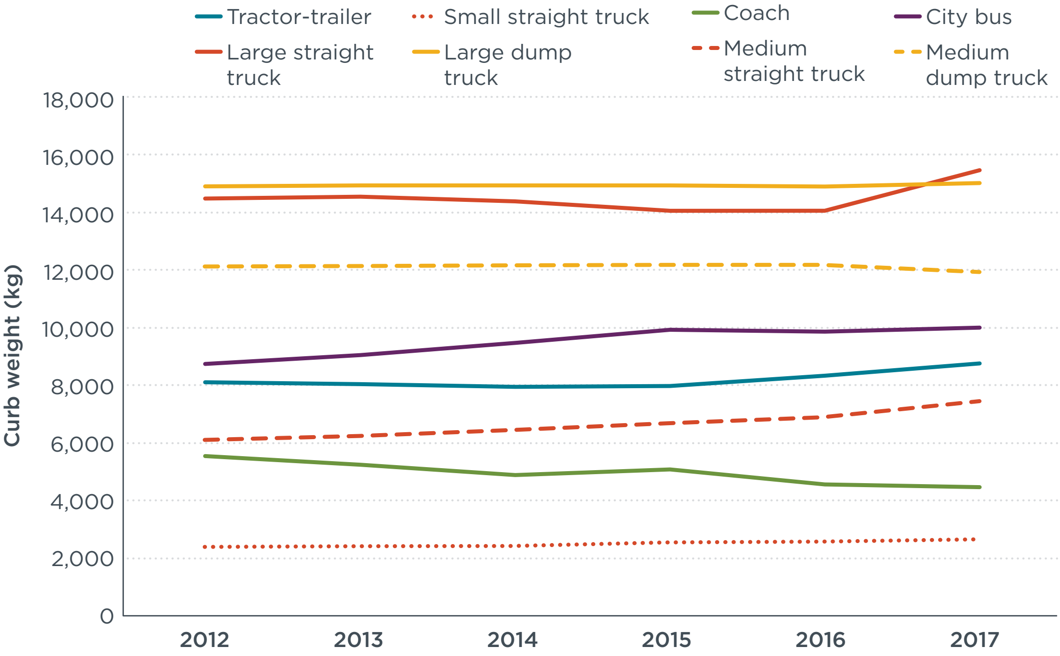

Figure 13. Average curb weight of each category by year. The reported GVW for tractor-trucks in this figure does not include trailers.

Wheelbase and footprint

As the data shown in Figure 14 suggests, the increase in the curb weight of medium and large straight trucks described above is not a consequence of larger wheelbases and footprints, as those metrics have stayed relatively constant for most of the vehicle segments. In the lighter segments, there are two opposing trends. While the footprint of coaches has decreased since 2012, that of small straight trucks has increased by approximately the same magnitude in the same time period. Given that the wheelbase of small straight trucks has stayed relatively constant, an increase in footprint area can only be explained by an increase in track width.

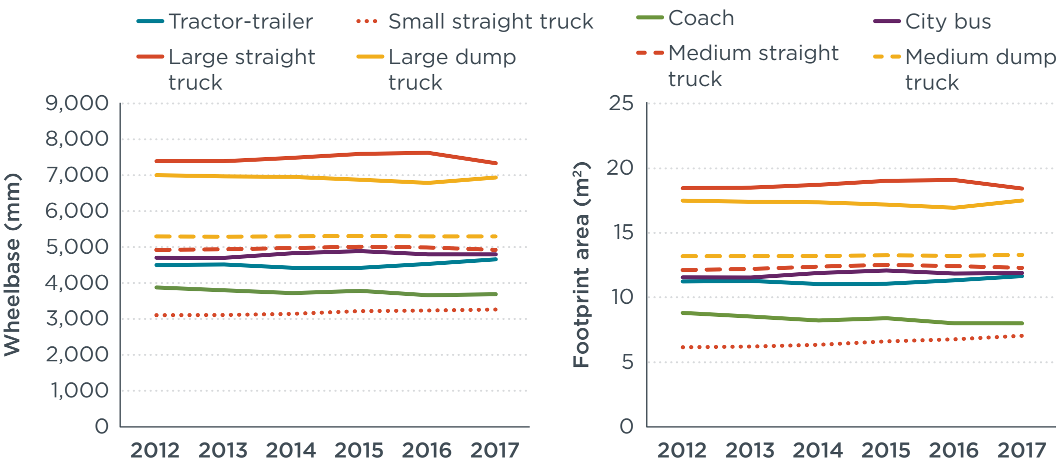

Figure 14. Average wheelbase (left) and footprint area (right) for each category by year.

CERTIFIED FUEL CONSUMPTION PROGRESS OF HDVS DURING 2012–2017

In most segments of HDVs, there has been limited improvement in fuel consumption since the introduction of Stage 1 and Stage 2 standards. Among the segments analyzed, city buses displayed the most substantial improvement during the evaluation period, with a reduction in fuel consumption of approximately 27% in 2017 compared with 2012; this likely is the result of the deployment of fuel efficiency technologies (e.g., hybrid powertrains and kinetic energy recovery systems) that were incentivized by local governments. However, in the dump truck and tractor-trailer segments, two vehicle categories with relatively high sales volumes, there was some deterioration since the implementation of the fuel consumption standards.

Figure 15 shows the range of certified fuel consumption for each segment during the evaluation period. Overall, city buses, medium dump trucks, and coaches are the segments with largest change. In the medium straight truck, large straight truck, and small straight truck segments, there was less improvement. Details of progress by segment are included in the next sections.

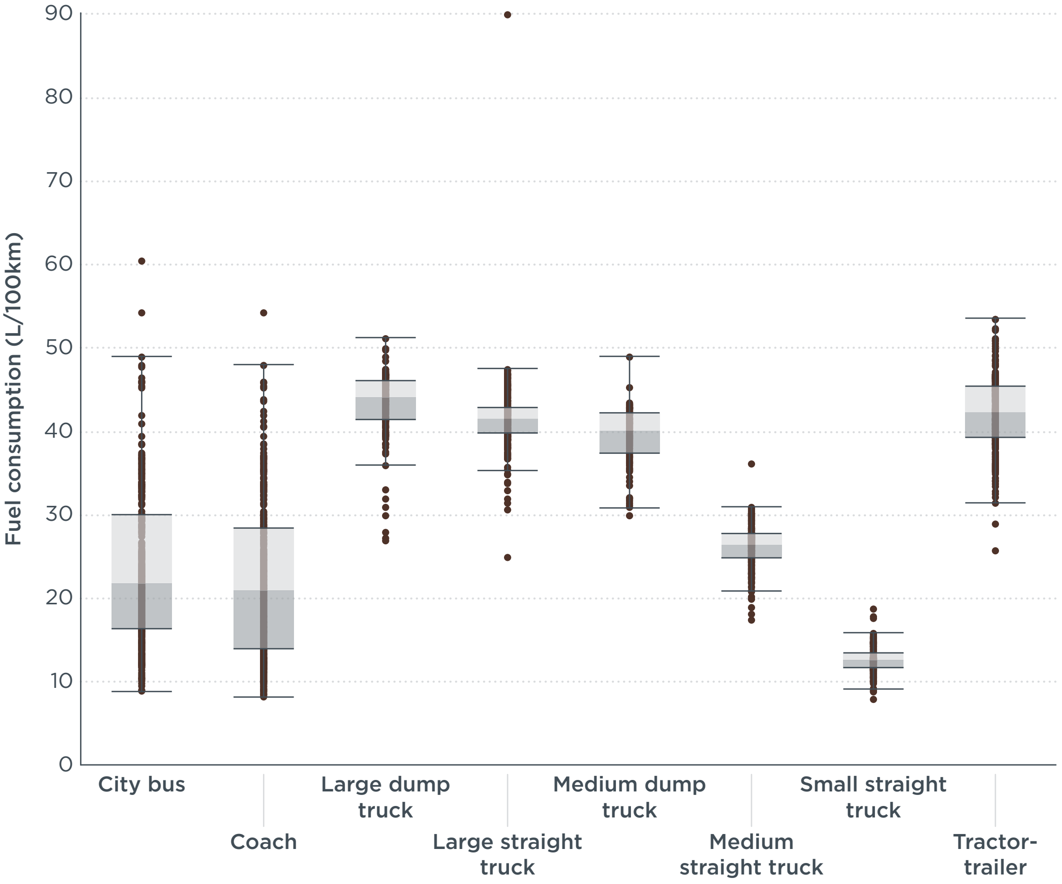

Figure 15. Boxplot of the certified fuel consumption for each segment during the evaluation period. The whiskers cover 1.5 times the interquartile range of the data and the box covers the range from the 25th to 75th percentile.

Table 3 summarizes the percentage of vehicles that already complied with Stage 3 standards in 2017. For city buses, 34.6% of models produced in 2017 already met the requirement for Stage 3, and for all models (for buses and all other segments) for which fuel consumption values were unavailable, we assumed they failed to meet the standard. Additionally, 26.2% of coach models and 18.8% of large straight truck models already outperformed Stage 3 standards in 2017, almost 2 years ahead of the official implementation date.

Table 3. Percentage of HDVs compliant with Stage 3 in 2017, by segment

Segment	Percentage of vehicles compliant with Stage 3 in 2017[a]
Small straight truck	14.8 %
Tractor-trailer	8.5 %
Coach	26.2 %
Medium straight truck	1.1 %
Large dump truck	6.8 %
Large straight truck	18.8 %
Medium dump truck	2.9 %
City bus	34.6 %

[a] All models for which fuel consumption values were not available were assumed to fail to meet Stage 3 standards.

SMALL STRAIGHT TRUCK

Small straight trucks, which have a GVW between 3.5 and 4.5 tonnes, saw a reduction in fuel consumption of more than 12% during the analyzed period, from 13.8 L/100 km in 2012 to 12.1 L/100 km in 2017. For this sub-segment, the Stage 1 and Stage 2 standards set the fuel consumption limit at 15.5 L/100 km and 13 L/100 km, respectively.

While the number of small straight trucks sold in 2012 and 2017 was nearly identical (563,333 in 2012 and 578,027 in 2017), Figure 16 below only shows vehicles for which a certified fuel consumption value was included in the dataset. Therefore, a great portion of data points are not displayed for 2012 and 2013, as the certified fuel consumption was not available for 80% of the models in those years.

As shown in Figure 16, the biggest impact of Stage 2 standards on the small straight truck segment was the phase out of the worst performing vehicles; these took up less than 0.5% of total sales under Stage 1. These worst performers had a negligible impact on the average fuel consumption. Moreover, 97.7% of the small straight trucks already complied with Stage 2 standards before 2015, and more than 99% of new sales after 2015 met the Stage 2 standard, despite the reality that models approved before the implementation of Stage 2 were allowed to be sold until July 1, 2015. This finding is even more striking when we consider that utility vehicles were not yet required to comply with fuel consumption standards.[5] Around 14.8% of small straight trucks also complied with the upcoming Stage 3 standard almost 2 years ahead of its implementation.

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[5] In the Chinese context, utility vehicles includes vehicles with specific purposes, such as sanitation vehicles, environmental monitoring vehicles, engineering vehicles, and ambulances, and others.

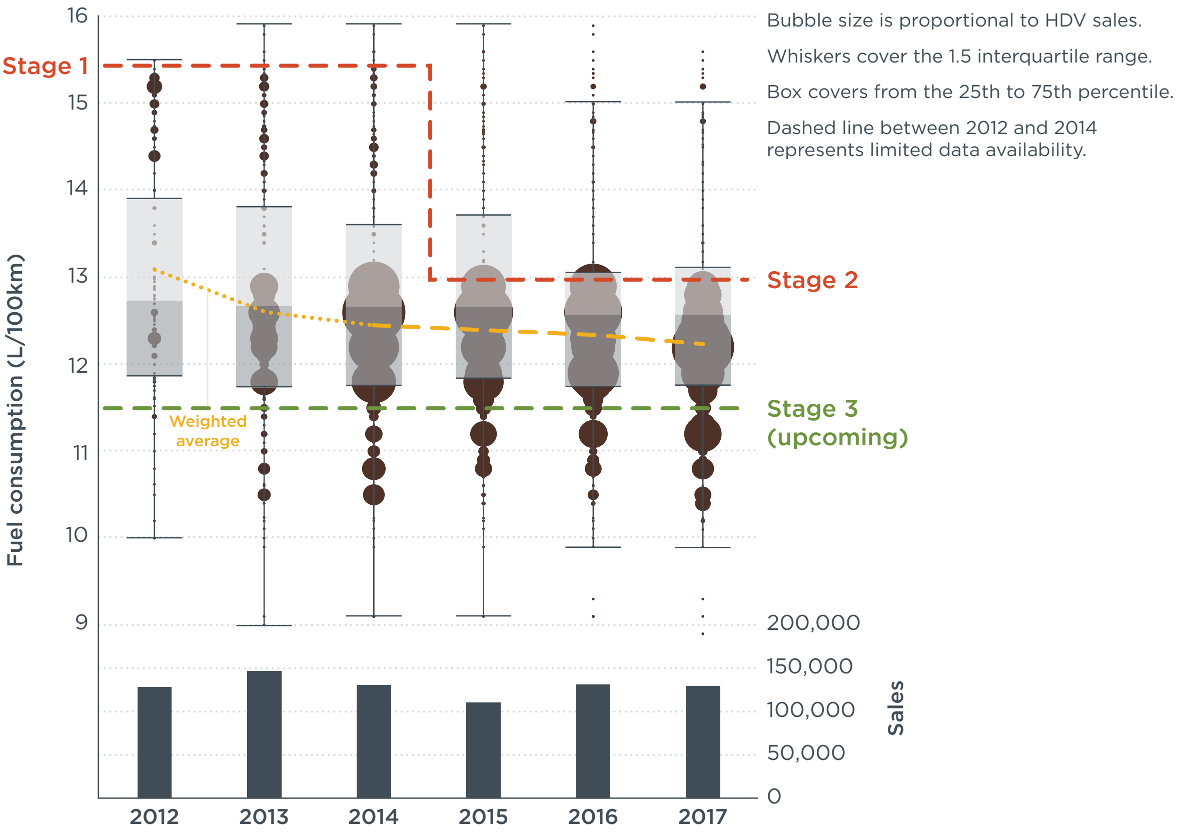

Figure 16. Certified fuel consumption of small straight trucks, 2012–2017.

TRACTOR-TRAILER

The tractor-trailers considered in this study are of GCW between 46 and 49 tonnes. The average fuel consumption was 42.6 L/100 km in 2012, and then increased to 45.4 L/100 km in 2015; it then slightly decreased to 44.7 L/100 km in 2017 (Figure 17). Figure 17 shows vehicles only with available certified fuel consumption in the dataset, which, due to missing data in the early years of the evaluation period, only accounted for 10.1% in 2012, 20.6% in 2013 and 46.2% in 2014, respectively.

Tractor-trailers have been regulated since Stage 1, when the certified fuel consumption limit was 54.0 L/100 km. The Stage 2 limit was adjusted downward by 13% to 47.0 L/100 km. Stage 3 required an additional reduction of 15% to 40.0 L/100 km.

As shown in Figure 17, the implementation of Stage 2 in 2015 had little impact on the certified fuel consumption of tractor-trailers. In 2014, 91.7% of tractor-trailers were already compliant with the Stage 2 limit. Additionally, 8.5% of tractor-trailers in 2017 were already compliant with Stage 3.

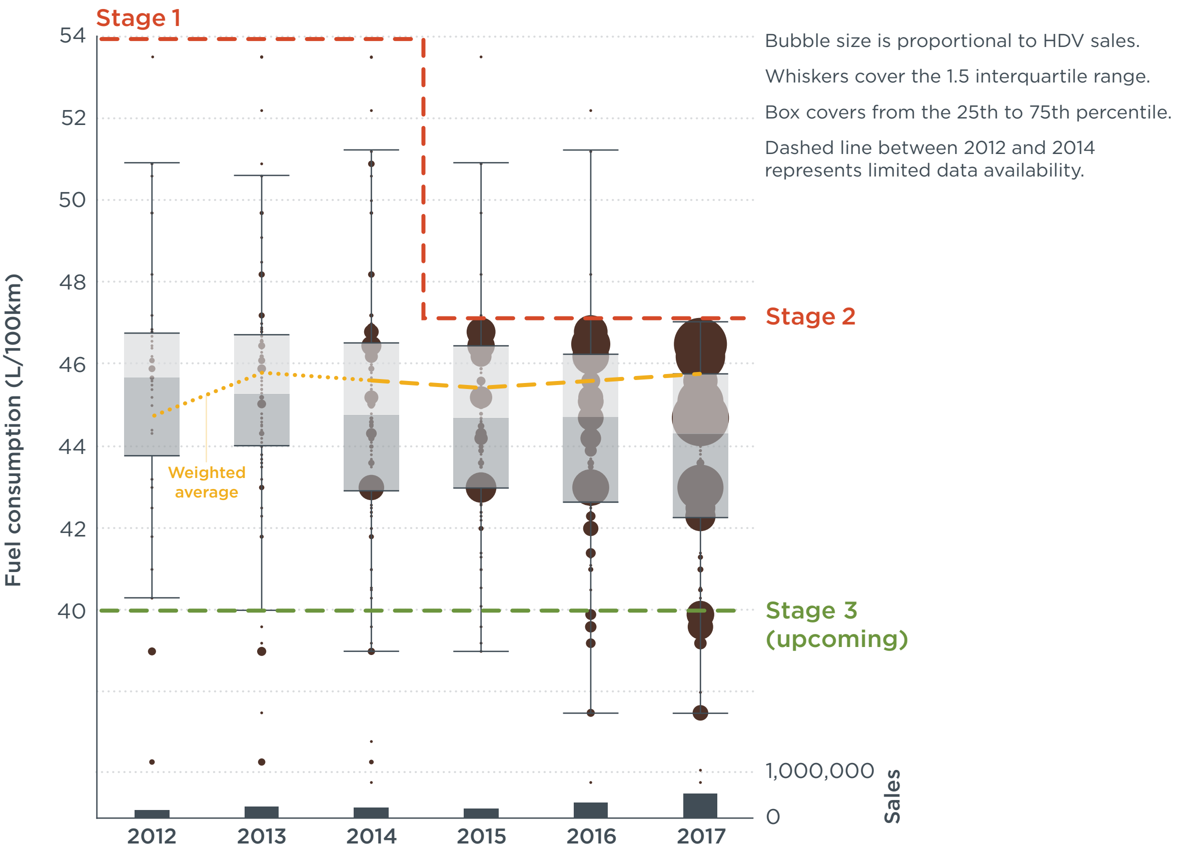

Figure 17. Certified fuel consumption of tractor-trailers, 2012–2017.

COACH

In this study, coaches with GVW between 3.5 and 4.5 tonnes were highlighted for analysis, as sales within this range were 40%–60% of total units sold in years during the evaluation period. Coaches have been regulated since Stage 1, when the limit was 14.0 L/100 km. While Stage 2 updated the fuel consumption limit to 12.5 L/100 km, the fuel consumption distribution of light coaches did not change between 2014 and 2016. That is, coach manufacturers did not have to add or upgrade any technology in their products to meet Stage 2 standards.[6] Furthermore, the analysis shows that 26.2% of new coaches sold in 2017 already meet the Stage 3 limit of 10.6 L/100 km. Still, a general downward trend can be witnessed for this segment during the last years of the evaluation period. The average fuel consumption was 10.8 L/100 km in 2017 after peaking at 11.2 L/100 km in 2015.

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[6] In 2017, 7% of coaches still exceeded Stage 2 standards. No explanation for this was found as of the time of publication.

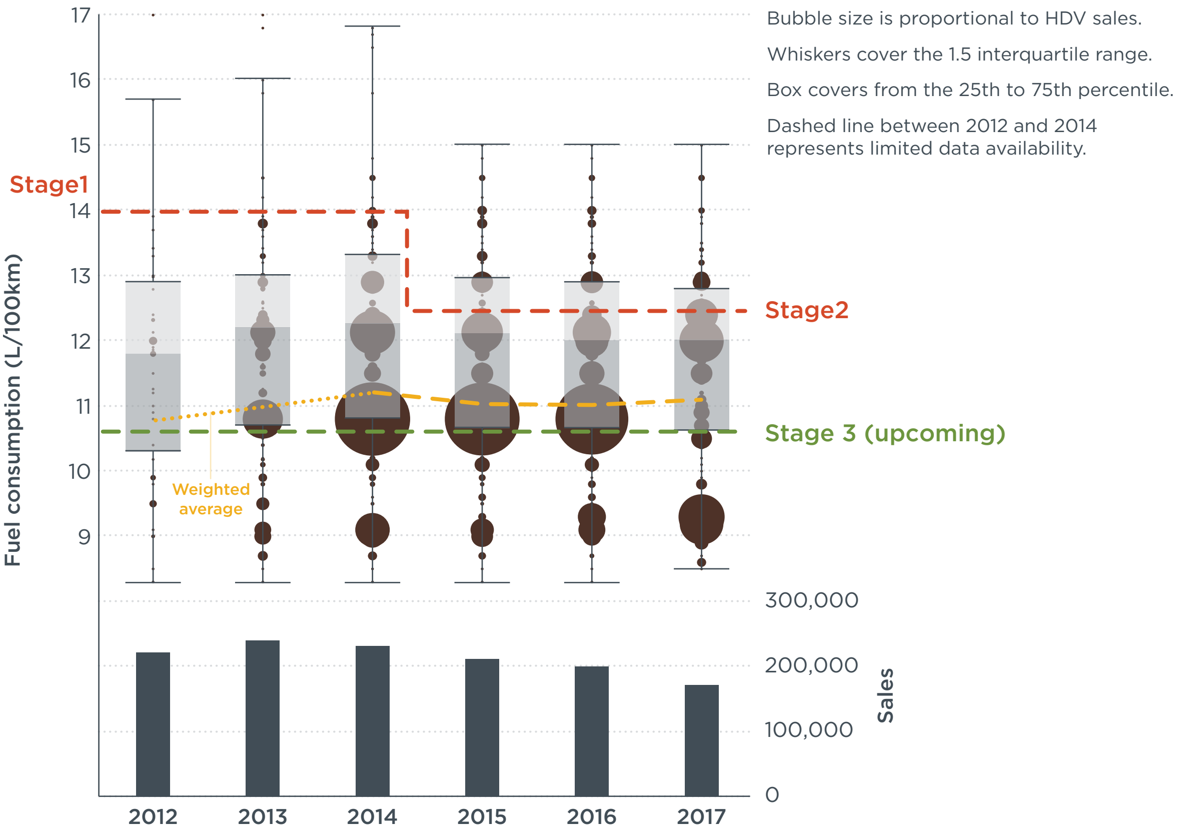

Figure 18. Certified fuel consumption of coaches, 2012–2017.

MEDIUM STRAIGHT TRUCK

Straight trucks with GVW between 12.5 and 16 tonnes are categorized as medium straight trucks, and the average fuel consumption of this segment slightly declined from 27.4 L/100 km in 2012 to 26.1 L/100 km in 2017. Most of the reduction took place between 2012 and 2014, and from 2014 onward, the certified fuel consumption of medium straight trucks has been stagnant. As with other vehicle segments already discussed, Stage 2 standards had a negligible impact on the certified fuel consumption of medium straight trucks.

However, given that only a small portion of vehicles (about 1.1%) are already compliant with the Stage 3 limit of 24 L/100 km, it is expected that the certified fuel consumption of this segment will improve with the implementation of Stage 3.

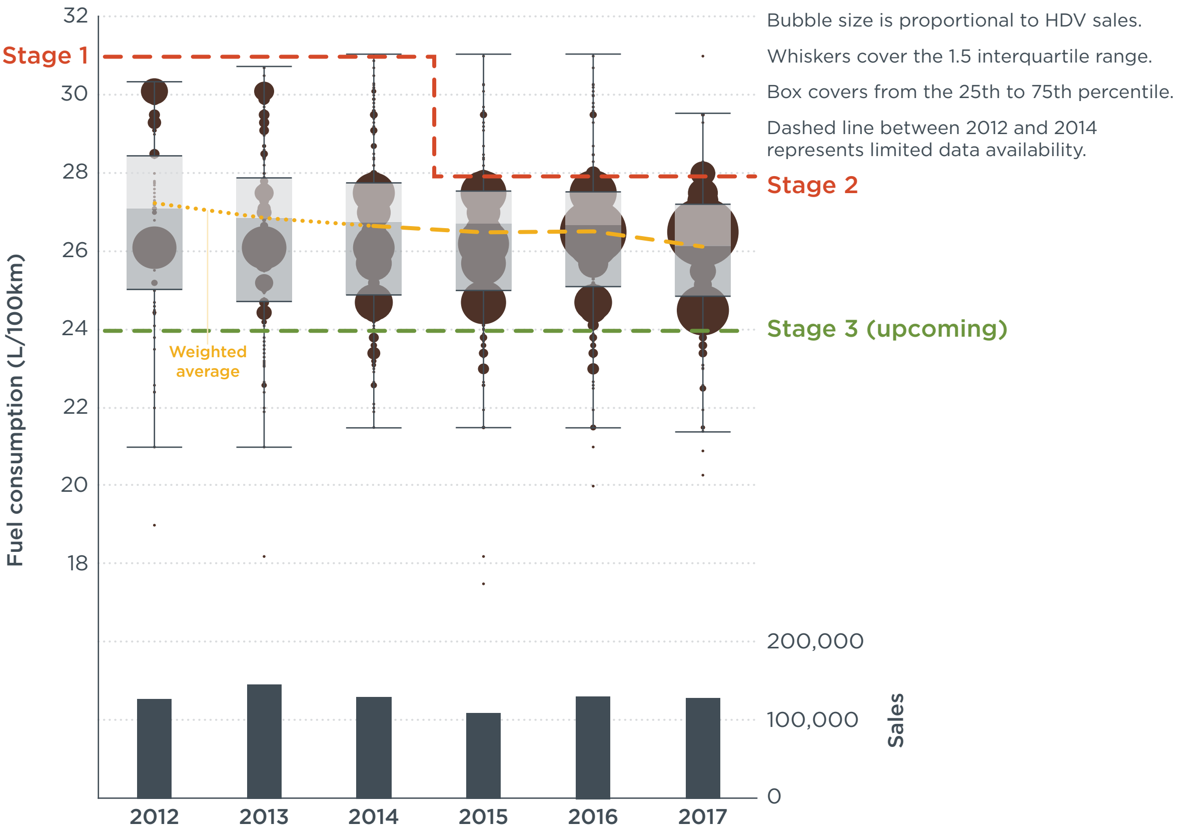

Figure 19. Certified fuel consumption of medium straight trucks, 2012–2017.

LARGE DUMP TRUCK

The large dump truck segment comprises all dump trucks with GVW between 25 and 31 tonnes. During the evaluation period, the average certified fuel consumption of large dump trucks increased slightly, by about 2%. Large dump trucks were not covered by Stage 1 fuel consumption standards, and Stage 2 set an upper limit of 47.0 L/100 km. While Stage 2 had no impact on the certified fuel consumption of this segment, it is evident that a large portion of the trucks are close to the Stage 2 limit. Stage 3 tightens that limit, and requires that large dump trucks have a maximum certified fuel consumption of 41.0 L/100 km. Only 6.8% of vehicles produced in 2017 were already compliant with the Stage 3 standard (see Figure 20); therefore, it is expected that the certified fuel consumption of this segment will improve with the implementation of Stage 3.

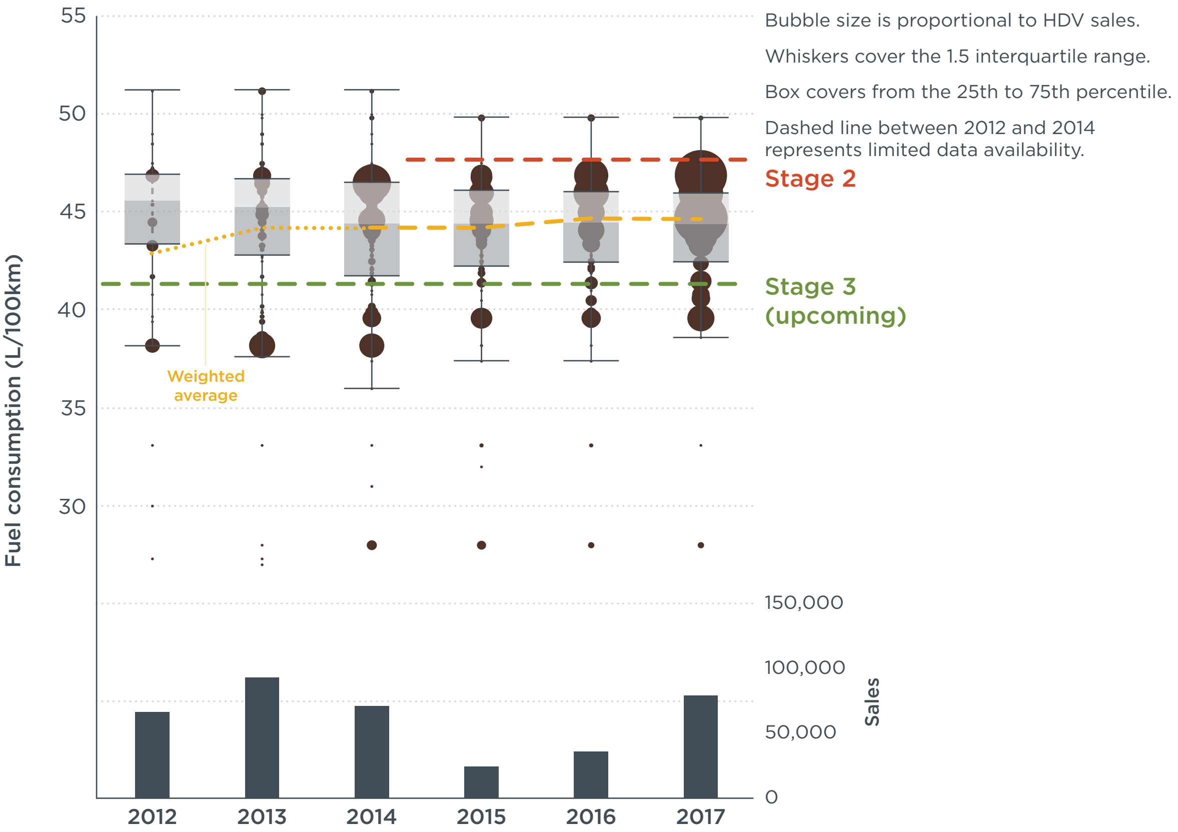

Figure 20. Certified fuel consumption of large dump trucks, 2012–2017.

LARGE STRAIGHT TRUCK

The large straight truck segment comprises all straight trucks with GVW between 25 and 31 tonnes. As with small straight trucks, our analysis only captures vehicles for which the certified fuel consumption was available in the dataset. Therefore, only a small portion of large straight trucks are shown in 2012 (2.3%) and 2013 (9.7%).

Generally, large straight trucks improved by 1.5 L/100 km from 2012 to 2017, reaching an average certified fuel consumption value of 40.4 L/100 km in 2017.[7] Most of this improvement occurred between 2016 and 2017. By 2019, Stage 3 mandates a maximum certified fuel consumption of 37.5 L/100 km; that is, approximately 3 L/100 km lower than the average certified fuel consumption in 2017. In 2017, 18.8% of trucks already complied with Stage 3 requirements (see Figure 21).

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[7] In the large straight truck segment, there were some vehicles produced after implementation of the Stage 2 standard which did not meet the standard. These are understood to be utility vehicles that fall outside the scope of the standards.

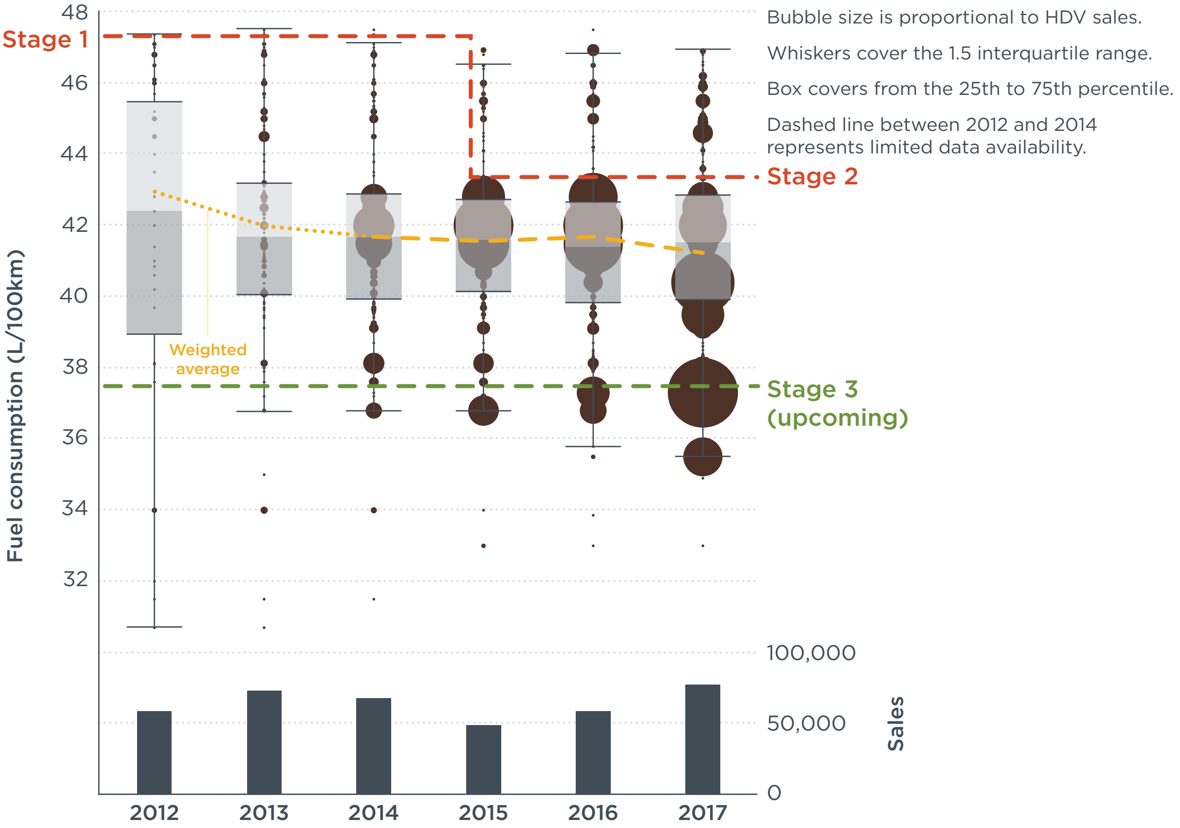

Figure 21. Certified fuel consumption of large straight trucks, 2012–2017.

MEDIUM DUMP TRUCK

Medium dump trucks are categorized here by GVW between 20 and 25 tonnes. Although our analysis shows the average fuel consumption of this segment grew by 12% between 2012 and 2017, the fuel consumption levels may be underestimated for the early years, as available data accounted for only 3.1% and 8.3% of all vehicles for 2012 and 2013, respectively. In 2014, for which we have data for 33% of vehicles, all vehicles sold were already compliant with the Stage 2 fuel consumption standard of 43.5 L/100 km; this was one year prior to its implementation. As shown in Figure 22, 30% of new medium dump trucks had a fuel consumption of around 42 L/100 km in 2017. The upcoming Stage 3 standard sets a more challenging target for medium dump trucks at 37.5 L/100 km; only about 2.9% of vehicles in 2017 already met the Stage 3 requirement.

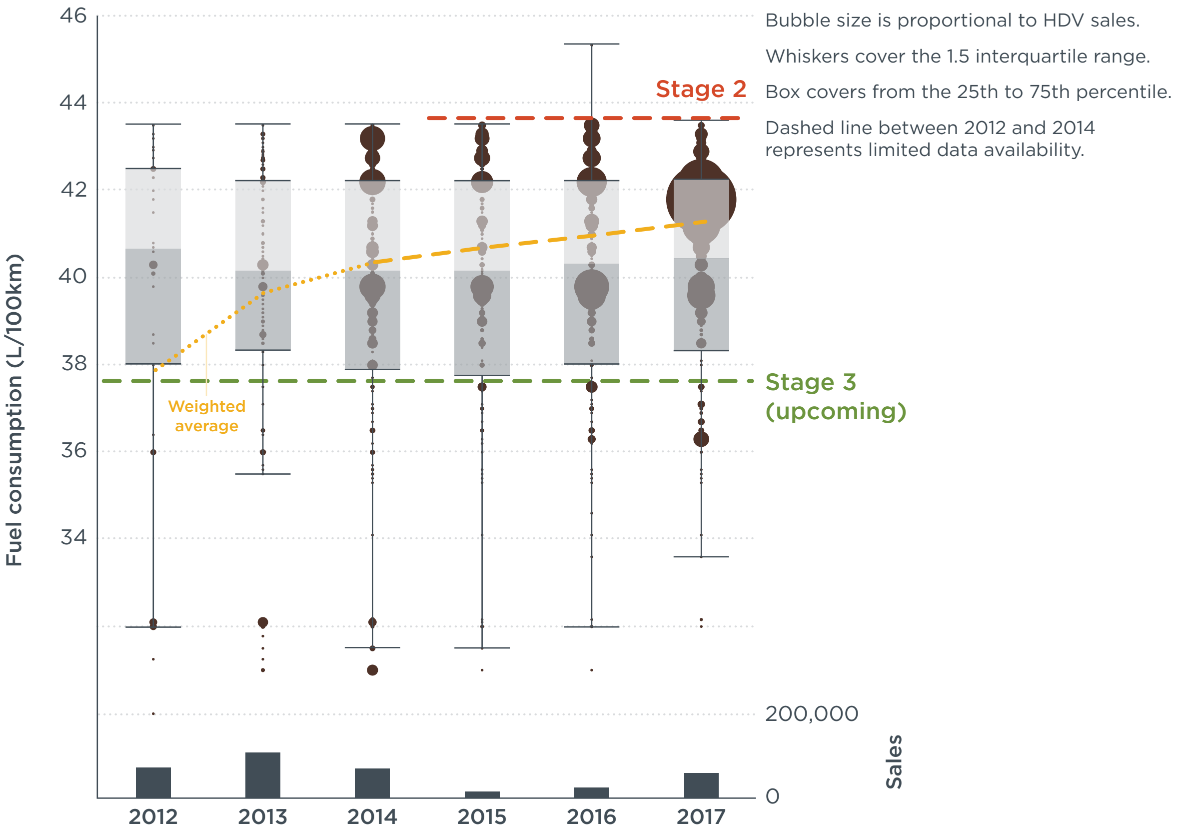

Figure 22. Certified fuel consumption of medium dump trucks, 2012–2017.

CITY BUS

This study focuses on city buses with GVW between 14.5 and 18 tonnes, since they represent about half of the sales volume of this segment. Overall, the average certified fuel consumption was reduced by 27% between 2012 and 2017, from 29.5 L/100 km to 21.6 L/100 km. City buses were first covered by Stage 2 with a 37.5 L/100 km limit. The Stage 3 standards adjust the limit downward by 6 L/100 km. However, the impact of Stage 3 is expected to be limited, given that our analysis shows that 34.6% of buses in 2017 are already below the Stage 3 limit (see Figure 23).

The reason that city buses have exhibited more progress than other categories is that, over the past decade, Chinese authorities cut down fuel consumption by replacing models with hybrid powertrains (L. Li, 2009) and by using aerodynamics techniques and kinetic energy recovery systems (Man, 2015) in Beijing, Jinan, and other cities. Thus the requirements set by both Stage 2 and Stage 3 have lagged behind the technology progress seen in city buses and are not expected to have brought—or to bring in the case of Stage 3—any significant additional adoption of fuel saving technologies.

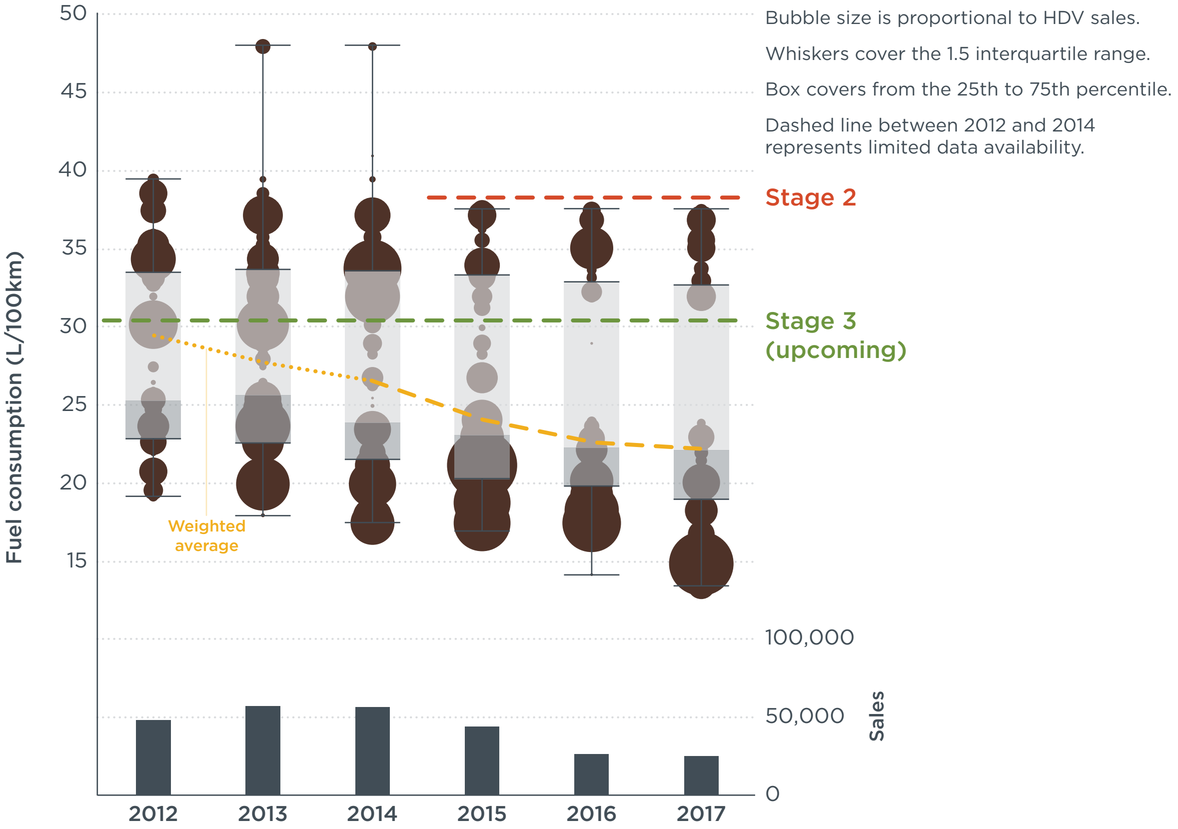

Figure 23. Certified fuel consumption of city buses, 2012–2017.

DISCUSSION: REAL-WORLD VERSUS CERTIFIED FUEL CONSUMPTION

Data about the real-world fuel consumption of HDVs in China is scarce. Although a few case studies measured the fuel consumption of HDVs in China in the last decade (Feng et al., 2019; Huang et al., 2010), these results cannot be directly compared to the certified fuel consumption values, given differences in payload and drive cycle. Still, a study conducted by CATARC in 2019 found that the real-world value exceeds the certified value by 10.8%–88.0% on the China Heavy-duty Commercial Vehicle Test Cycle, or CHTC, and by 10.1%–76.6% on the C-WTVC driving cycle, China's modified version of the World Harmonized Vehicle Cycle, (Feng et al., 2019). This suggests that the gap between real-world and certified fuel consumption for heavy-duty vehicles can be significant, and warrants a closer look at the current certification methodology.

To quantify the impact of the different certification methodologies, we did a series of simulations of the fuel consumption of tractor-trailers over different driving cycles. A sensitivity analysis was performed by simulating a representative tractor-trailer over three drive cycles and by using three combinations of aerodynamic drag and rolling resistance coefficients, which combined are also called road-load parameters. The aim was to assess the sensitivity of the reported fuel consumption to both the driving cycle and the road-load parameters used for certification.

A key finding of this simulation exercise is that the flexibilities given to manufacturers during the fuel consumption certification have a significant impact on the certified fuel consumption. Manufacturers can reduce the costs associated with the fuel consumption certification by using default road-load parameters, instead of performing detailed component tests, and this is often the preferred option. The default values of rolling resistance and air drag that manufacturers can use in the certification of the fuel consumption are summarized in Table 4 and Table 5.

Table 4. Default values for the rolling resistance coefficient

Category	Tire type	Rolling resistance factor
GVW<14,000kg	Bias tire	f = 0.0076+0.000056*v
	Radial tire	
GVW≥14,000kg	Bias tire	f = 0.0066+0.0000286*v
	Radial tire	f = 0.0041+0.0000256*v

Note: v is the vehicle velocity in km/h

Table 5. Default values for the air drag coefficient

Category	Coefficient
Tractor-trailer	0.8
Dump truck	0.8
Truck	0.8
City bus	0.65
Coach	0.65

Given the limits of Stage 1 and Stage 2 standards, we anticipate that manufacturers were able to comply by using the default road-load values shown in the tables above, without the need to conduct air drag or tire rolling resistance tests. This also means that manufacturers that choose to switch from using the default values to using measured ones for compliance purposes will likely see an improvement in the certified fuel consumption without there being any change in the vehicle itself, and therefore in its real-world fuel consumption. Thus the fuel consumption testing methodology can fail to incentivize improvements in the aerodynamic and rolling resistance performance of vehicles if the stringency of the standard does not require it.

Driving cycle is another critical aspect of fuel consumption certification. The profile of China's incumbent driving cycle, the C-WTVC (Figure 24), and that of the proposed new certification cycle, CHTC, are shown below (Figure *25*), both running with road grade as 0°. It should be noticed that CHTC is a collection of several specific standards for each segment, namely, CHTC-LT for light trucks, CHTC-HT for heavy trucks, CHTC-C for coaches, CHTC-TT for tractor-trailers, CHTC-D for dump trucks, and CHTC-B for city buses. The C-WTVC driving cycle was used for Stage 1, 2, and 3 standards. Even though that CHTC is ready for HDV fuel consumption testing, the associated testing procedure standard has not yet been finalized for future use; hence it is highly possible that the upcoming Stage 4 standards, currently under development, will transit to CHTC cycles as the only official certification testing procedure, once the testing procedure standard is determined in the near future.

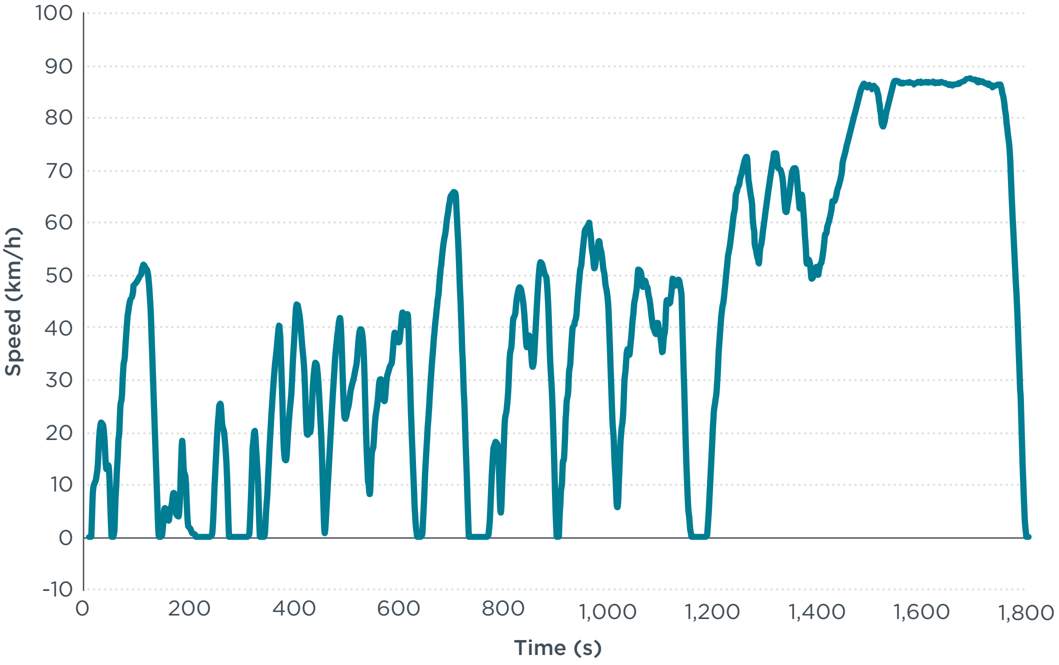

Figure 24. C-WTVC driving cycle

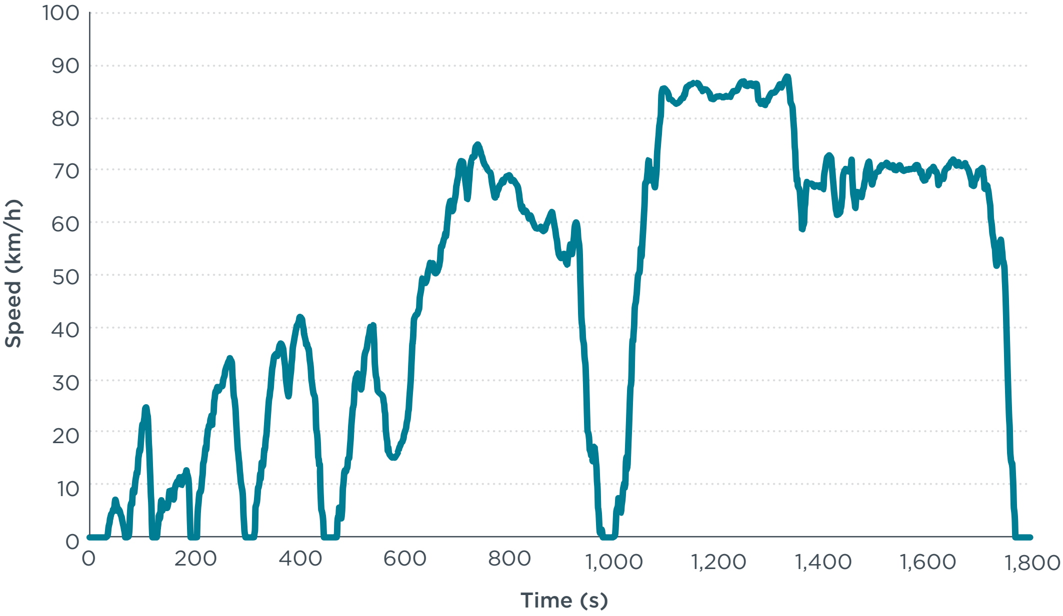

Figure 25. CHTC-TT driving cycle

The cycles used for our sensitivity analysis were the C-WTVC, CHTC-TT, and the European long haul (EU-LH). The EU cycle was used as it provides a comparison with the certification methodology used in another region. The three scenarios for road-load parameters were the current default values used for fuel consumption certification in China ("default"), estimates of the actual road-load parameters expected to be found in current vehicles ("measured"), and estimates of possible future performance of tractor-trailers ("future") informed by a previous ICCT study (Meszler et al., 2019). The road-load parameters used for these three scenarios are summarized in Table 3. All other vehicle parameters were obtained from a typical tractor-trailer from China and were kept constant throughout the analysis.

Table 6. Parameters used for the sensitivity analysis on the fuel consumption certification methodology in China

Scenario	C_D*A (m^2)	Rolling resistance coefficient (RRC)
Default	8	0.006
Measured	6	0.005
Future	4.5	0.004

Figure 26 shows the simulation results normalized by the values obtained with the *default* scenario. The first finding is that the default road-load parameters available for certification overestimate fuel consumption between 8% and 13% by driving cycles, compared to the *measured* scenario. Hence, by performing detailed aerodynamic and rolling resistance testing (i.e*., measured* scenario), manufacturers could report significant improvements in the certified fuel consumption without any improvements in the vehicle.

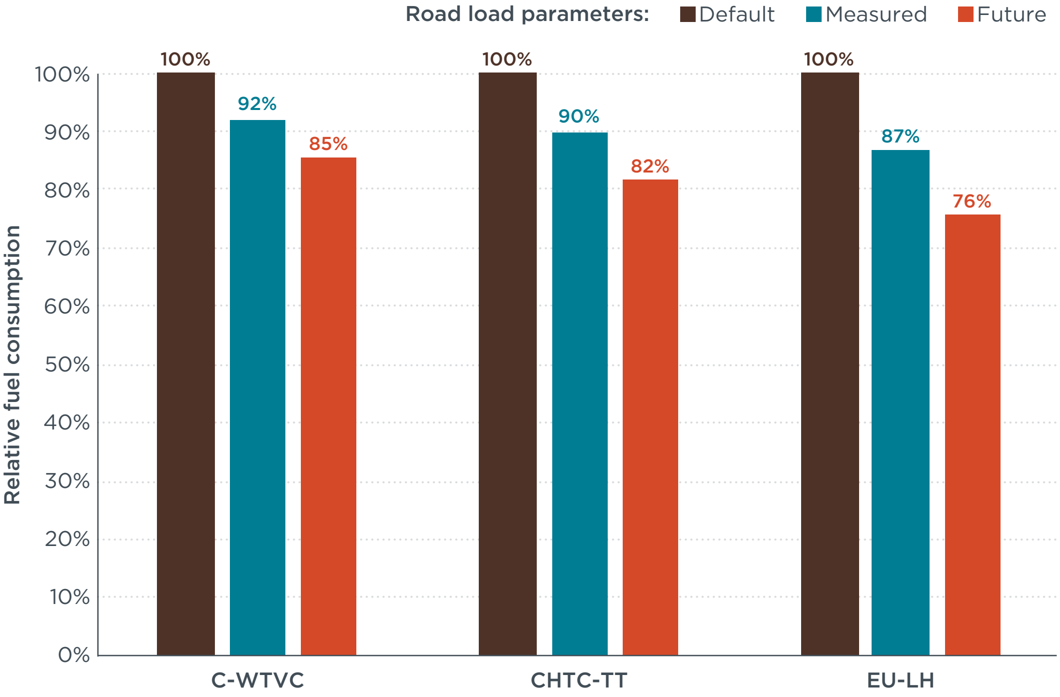

Figure 26. Fuel consumption simulation for a typical tractor-trailer in China with different road-load parameters and driving cycles.

The other key finding is that the choice of cycle has a significant impact on the reported fuel savings when applying road-load performance improvement. When analyzing the *future* scenario over the C-WTVC cycle, we estimate an improvement in fuel consumption of 15%, and the improvement is estimated to be 18% over the CHTC-TT. For comparison, the analysis over the EU-LH cycle yields a 24% improvement.

CONCLUSION AND POLICY RECOMMENDATIONS

China's fuel consumption standards have progressed substantially since they were first introduced, and Stage 4 standards are currently in development. This paper, covering all but electrified HDV registrations from 2012 to 2017, analyzed the improvement in fuel consumption that was driven by Stage 1 and Stage 2 standards. We examined the data of 10.5 million vehicles and the key findings of this ex-post analysis are:

» **Most Chinese trucks are increasing in size and power:** Between 2012 and 2017, the average curb weight of tractor-trailers increased by 9.0%, straight trucks between 6.8% and 18.5%, dump trucks between -1.3% and 0.6%. Similarly, the average engine power increased for most commercial vehicle segments; tractor-trailers increased engine power by 16%, straight trucks by between 11.2% and 20.0%, and dump trucks between 5.8% and 13.8%.

» **Stage 1 standards appear to have had no impact on certified fuel consumption:** The standards sought to establish minimum performance criteria for the different vehicle segments and did not result in the introduction of new fuel consumption technologies or in any measurable improvements in fuel consumption. Some outlier models with extremely high values were no longer approved to enter the market, though.

» **Stage 2 standards had a limited impact on certified fuel consumption:** Compared to the Stage 1 industry standard, the Stage 2 limits were adjusted downward by 10% to 15%, depending on vehicle segment. The improvement in certified fuel consumption, however, was much lower than that. After Stage 2 was introduced, some HDV segments exhibited a slight downward trend in fuel consumption, while others a slight upward trend. Most notably, city buses reduced their fuel consumption by more than 25% between 2012 and 2017. However, this improvement cannot be attributed to the Stage 2 standards, but rather to the incentives created by local governments and at the national level for the modernization of urban bus fleets. Dump trucks, on the other hand, increased their fuel consumption by 2% on average between 2012 to 2017, while still complying with Stage 2 standards.

» **Stage 3 standards are not expected to deliver benefits on the same order of magnitude as the tightening of the limits would suggest:** Compared to Stage 2, the Stage 3 fuel consumption limits were adjusted downward between 10% and 18%, depending on the segment. However, because a significant portion of the vehicles certified to Stage 2 were already compliant with Stage 3, the actual improvement in certified fuel consumption across the fleet will likely be less than the aforementioned range. Further, an improvement in certified fuel consumption does not necessarily result in better real-world performance. Given the widespread use of default—and rather conservative—road-load parameters for the certification of fuel consumption, Stage 3 requirements can be partly met through more detailed testing of the aerodynamic and rolling resistance performance without any introduction of new technologies or improvement of existing ones. Recall that Table 3 summarized the information about the portion of vehicles already compliant with Stage 3 in 2017 for each segment.

Based on our findings, we offer the following policy recommendations for the development of Stage 4 standards and the fuel consumption certification methodology used:

» **The stringency of Stage 4 standards can force new technologies into the market and improve the competitiveness of Chinese manufacturers in international markets:** Stage 4 standards present an opportunity to set a technology-forcing regulation that would exploit the cost-effective technology potential completely. ICCT's research shows that there is substantial potential to cost-effectively reduce the fuel consumption of HDVs in China. Available efficiency technologies can reduce fuel consumption by 23% compared to Stage 3 levels, and deliver payback periods to owners that are generally within 1.3 years or less (Meszler et al., 2019).

- **Certification drive cycles that are representative of real-world operation are fundamental for driving fuel-saving technologies to the market**: The current C-WTVC test cycle used for evaluating the fuel consumption of all HDVs in China will likely be replaced by six separate new cycles, the CHTC cycles, that cover the different heavy-duty applications. However, the drive cycles do not include any road grade provisions. The inclusion of road grade would be beneficial for the real-world representativeness of the certification process, and for incentivizing important fuel-saving technologies that thrive on mountainous topographies.
- **Road-load technologies are essential for improving the fuel consumption of trucks and buses, and could be incentivized better in Stage 4:** The Stage 1 and 2 stringency levels did not drive the deployment of technologies for the improvement of the aerodynamic drag, rolling resistance, and vehicle weight—collectively known as road-load technologies. Currently, manufacturers typically rely on default values of rolling resistance and aerodynamic drag for certification, and there is little incentive to perform detailed component testing or to deploy road-load technologies. Future certification procedures and the stringency of Stage 4 standards could incentivize the testing and deployment of those technologies. Further, manufacturers are not currently encouraged to develop lightweighting technologies for fuel saving because the vehicles are tested at their maximum allowable weight. That is, vehicles with lower curb weight that can have lower real-world fuel consumption do not receive any benefit during certification. By setting standardized payloads below maximum, the certification provision can not only improve the representativeness of the tests, but also drive the deployment of lightweighting.
- **China's fuel consumption certification could benefit from shifting from chassis dynamometer testing toward vehicle simulation:** Physical testing of HDVs on the chassis dynamometer is time-consuming and expensive, particularly when a large number of vehicle configurations are possible. As a consequence, several regions around the world use a combination of component testing and vehicle simulation for certification of the fuel consumption and CO_2 emissions of HDVs. While China already provides the possibility of certifying vehicle variants using a simulation tool, this certification pathway is currently rarely used. Further developing China's simulation model—for example, by improving the driver model and the associated shifting strategy—can incentivize the use of this certification pathway. In return, manufacturers will be able to benefit from the targeted deployment of fuel-saving technologies in different vehicle segments, and could pass on that purchase incentive to buyers.
- **The harmonization of component testing with international standards can decrease the compliance and certification costs of Chinese manufacturers with a global presence:** Standardized test methodologies for vehicle components have already been designed as part of fuel-efficiency and CO_2 standards in the United States and European Union. China can leverage these efforts during the development of standardized testing for aerodynamic drag, rolling resistance, engine fuel consumption, transmission losses, and others. This would allow China to focus on procuring the necessary technical knowledge and infrastructure to conduct standardized component testing. Harmonized component testing would also allow vehicle manufacturers and technology suppliers to certify in one country and sell in others. This would increase the opportunities for scale and reduce compliance costs.

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