



INCENTIVIZING VEHICLE MASS REDUCTION TECHNOLOGIES VIA SIZE-BASED PASSENGER CAR FUEL CONSUMPTION STANDARDS IN CHINA

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EXECUTIVE SUMMARY

As China is intending to roll out more stringent fuel efficiency standards for new passenger cars at an accelerated pace, regulators are looking at feasible near- to mid-term (2015–2020) vehicle fuel-saving technologies and their associated costs. Powertrain efficiency technologies—such as turbocharged gasoline direct injection, variable valve timing and lift, high-gear-count transmissions systems and/or continuous variable transmissions systems—that are increasingly adopted in the advanced vehicle markets will significantly, and at relatively low cost, cut vehicle fuel consumption toward meeting China’s 2015 target and play a major role in meeting its preliminary target for 2020. Vehicle mass reduction is an important non-powertrain technology option to meet the 2020 fleet target of 5L/100 km (NEDC), or 36% reduction from today’s level. Compared with the more expensive electrification technologies, vehicle mass reduction technologies are significantly more cost-effective (WAS, 2011; NHTSA, 2012; Lotus, 2012; EPA, 2012a; Meszler et al., 2013; Mock 2011; EC, 2012; TNO et al., 2011). A regulatory system that fully rewards mass reduction technologies reduces the compliance costs for manufacturers to meet stringent fuel saving targets, enhancing the chance of meeting these targets.

Regulators from around the world have realized that using a vehicle’s physical attribute to set efficiency standards reduces the competitive impact on automakers while preserving the goal of reducing fuel consumption. China’s previous and current fuel consumption standards are indexed to vehicle weight. Alternatively, vehicle size (more precisely footprint, or the area defined by the four wheels) has been adopted as the utility parameter to set vehicle efficiency standards in the United States and Mexico. This paper mainly discusses why China needs to shift to a vehicle footprint-based efficiency standard, and how the compliance burdens on auto manufacturers might change if such a standard is adopted. To this end, we constructed a set of US-styled piece-wise footprint-based standard curves that match China’s 2015 and 2020 fleet-average targets—6.9 and 5 L/100 km, respectively.

Vehicle weight is closely correlated with fuel consumption. A weight-based standard therefore reduces the incentive of applying mass reduction technologies as an important way to improve fuel economy. In contrast, a footprint-based standard is more technology-neutral than a weight-based standard, as it fully accounts for the adoption of lightweight materials and design. Thus, it will reduce the cost of compliance and enable more stringent standards to be set in the future. Footprint serves as a proxy for vehicle size, which unlike mass is an attribute valued by consumers and is less susceptible to gaming than vehicle weight.

Some argue that a very flat standard curve based on vehicle mass may help prevent from overall mass increase of the fleet. In practice, no matter how flat the standard curve is—as long as there is a non-zero slope—a weight-based system always penalizes mass reduction as it assigns more stringent targets for lighter-weight vehicles. As a result, lightweighting, or reducing the weight of a vehicle, is valued differently under weight- and size-based efficiency standard systems, as illustrated in Figure ES.1.

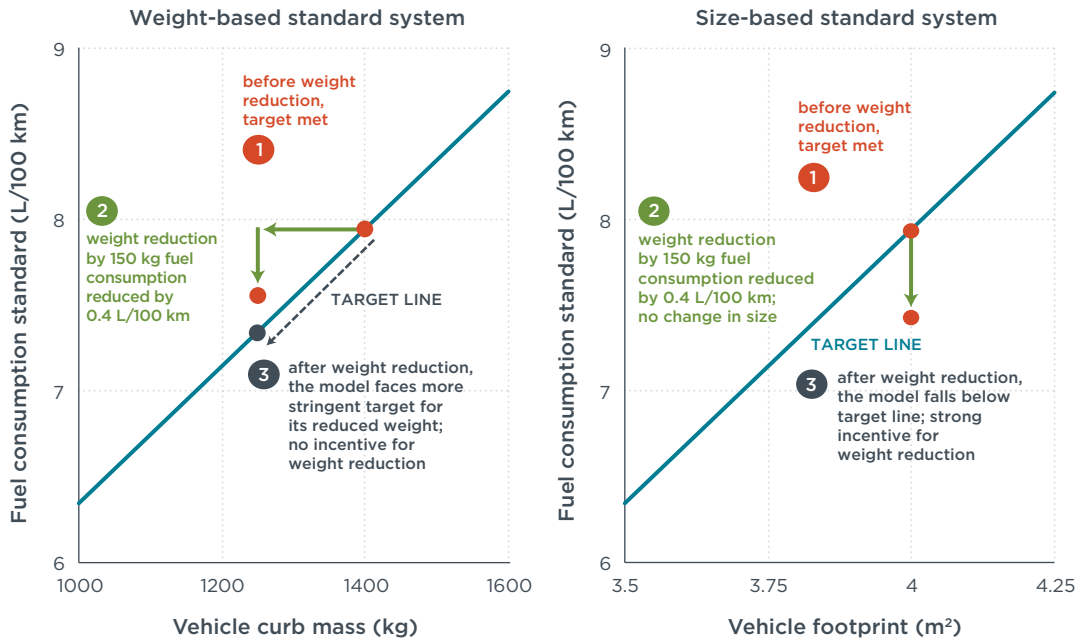


Figure ES.1. Illustration of varying impact on vehicle weight reduction under weight- and size-based fuel efficiency standard systems

Figure ES.2 illustrates our hypothetical footprint-based standard curves for 2015 and 2020. Figure ES.3 compares the corporate-average fuel consumption (CAFC) targets by 2015 under China’s current Phase 3 standard (orange data markers) and the hypothetical footprint-based standard (blue data markers). Top 20 manufacturers by market size are labeled in orange font. It appears that the largest manufacturers will face similar CAFC targets under both standard schemes in the near-term, but technology trajectory and costs under the two schemes can be different for different manufacturers. It appears that the footprint-based standard imposes tougher targets for manufacturers of heavier vehicles.

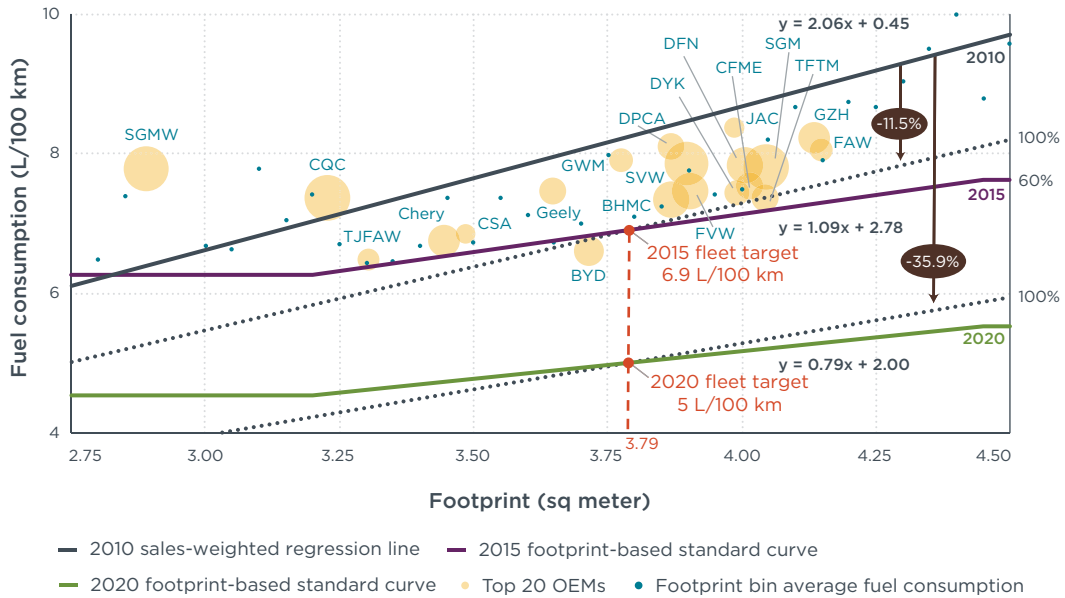


Figure ES.2. Piece-wise footprint-based standards for meeting China’s 2015 and 2020 new passenger car fleet fuel consumption targets

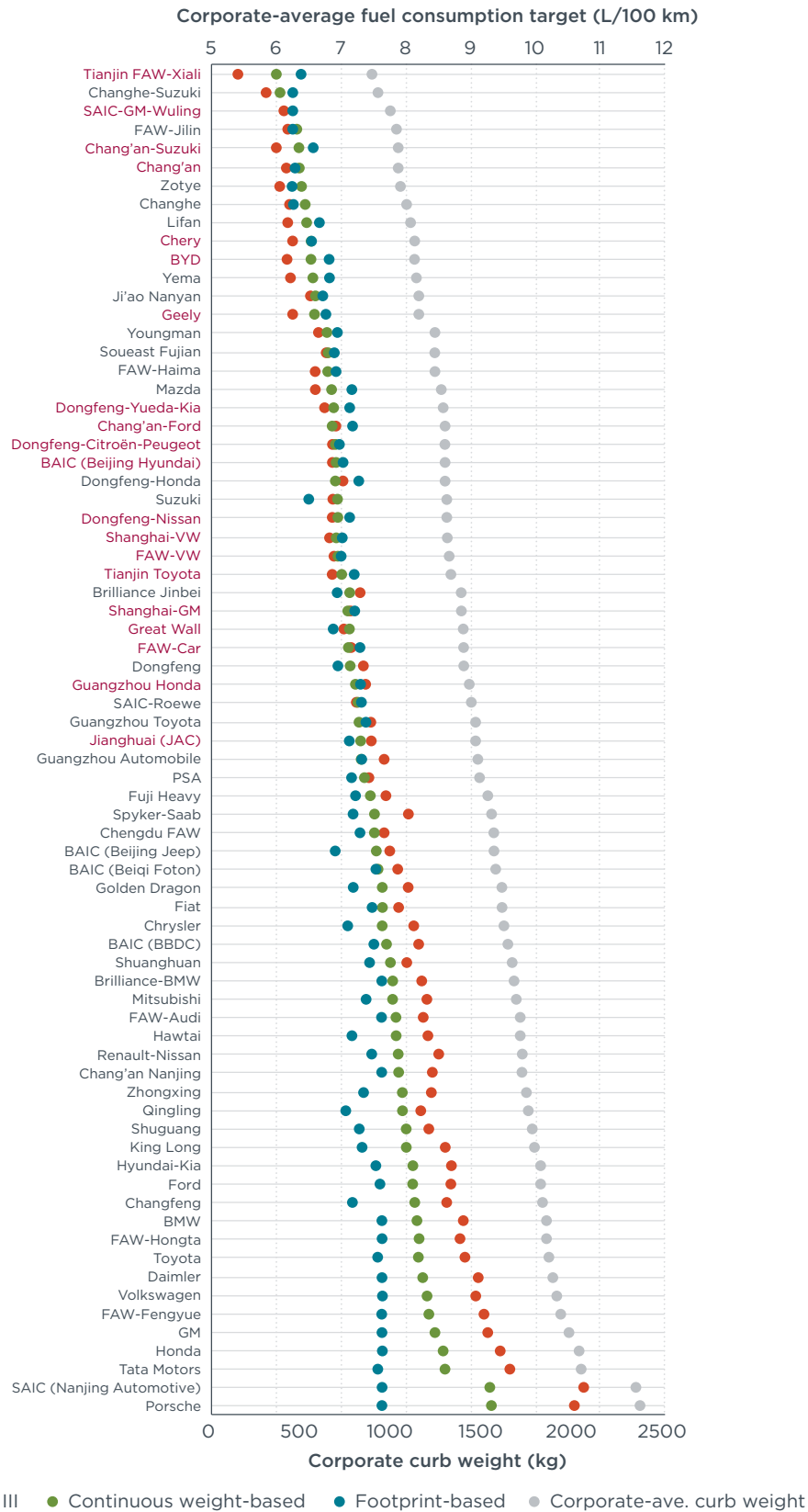


Figure ES.3. Comparison of CAFC targets for all manufacturers with manufacturers ranked by corporate-average fleet curb weight

This paper also includes an interim scenario of a continuous weight-based vehicle standard, similar to that adopted in the EU for passenger car CO₂ emissions regulation. This slight variation from China’s current weight category-based standard is developed to reflect some minor benefits—minimizing gaming in vehicle weight—of moving from a category-based standard structure to a continuous weight-based standard structure. Nevertheless, this hypothetical continuous standard suffers the fundamental setback of discouraging mass reduction technologies. And, as illustrated in Figure ES.3, the continuous weight-based standard (green data markers) favors heavier vehicle makers compared with the footprint-based standard, even though both hypothetical standard curves adopt a 60% slope.

It is noteworthy to distinguish between the near-term and long-term impact of a footprint-based vehicle efficiency standard. Near-term effects of a footprint-based standard from our study, in terms of changes in absolute CAFC target value for the major manufacturers, do not appear to be significant. This is primarily due to the high correlation between vehicle weight and footprint in today’s Chinese market. Such correlation may weaken in the future as more mass reduction technologies are phased in. Car manufacturers in China have already been deploying and developing vehicle mass reduction technologies, albeit in a limited manner as reflected in the weight variation of given vehicle size classes with similar power performance (Figure ES.4). However, the full potential of mass reduction technologies cannot be realized without the removal of the regulatory hurdle posed by a mass-based standard.

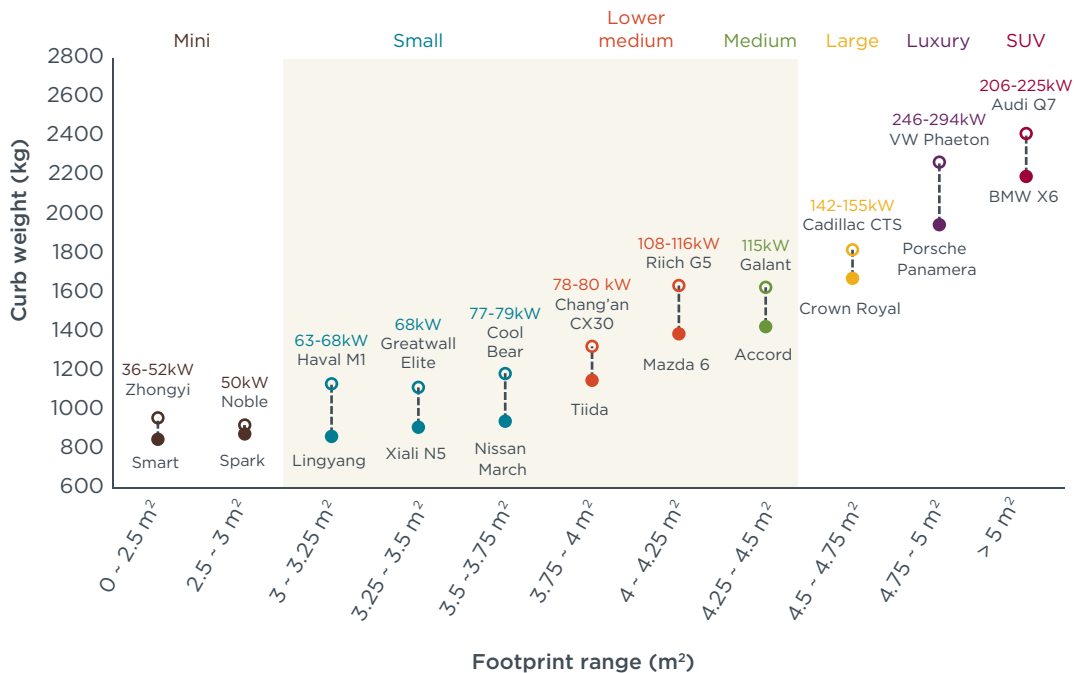


Figure ES.4. Range of curb weight of vehicles with similar horsepower, by footprint bin and market segment in China. Shaded area represents about 57% of sales by segment, or 88% of sales by vehicle size.

The paper arrives at the following conclusions:

- » A footprint-based standard is more technology-neutral than a weight-based standard, and therefore reduces compliance costs for manufacturers to meet more stringent long-term targets.
- » Our hypothetical footprint-based standard better rewards manufacturers producing lighter vehicles and penalizes heavier vehicles, compared with weight-based standard of the same slope choice, without altering the overall fleet fuel consumption targets for 2015 or 2020.
- » Our hypothetical footprint-based standard does not discriminate against or artificially favor either joint venture automakers or Chinese independent OEMs.
- » A continuous weight-based standard system offers a minor benefit of minimizing gaming in vehicle weight, leveling the playing field for manufacturers.

Based on the findings of this paper, we arrive at the following recommendations for China:

- » If China would like to stick to a vehicle utility parameter to set its fuel consumption standards, vehicle footprint is a better choice than curb weight to enable all efficiency improvement technologies, including vehicle mass reduction. Lightweighting will be a vital option globally, and the Chinese vehicle fuel consumption standard system should anticipate this trend by allowing this as a vital option.
- » If data are not complete enough to set footprint-based standards immediately, changing from the current weight bin-based standard to a continuous linear weight-based standard with a flatter slope than the current one will offer some important benefits.
- » While the structure of the standard is critical, other design elements also determine its stringency and overall effectiveness. These elements include:
 - » The slope of the standard curves should be low enough to avoid gaming and fleet upsizing/weight increase.
 - » The pivot point/center of gravity of a linear standard curve should reflect the regulatory target of the entire fleet.
 - » If necessary, the fuel consumption target can be capped (set constant beyond a particular footprint or weight level) for the largest or heaviest vehicles to further avoid upsizing/weight increase.

1 INTRODUCTION

Rapid growth in the number of vehicles and subsequent fuel use has been the motivation for the regulatory mandates on fuel efficiency of new vehicles in China. Starting in 2004, China adopted three phases of fuel consumption limits for passenger cars, as illustrated in Figure 1. Starting from the third phase, China has adopted its first corporate-average standard for new passenger fuel consumption, with an estimated fleet-average fuel consumption target of 6.9 L/100 km for all new passenger cars by 2015.¹ The gradually tightened target limits are shown in Figure 1. More details of the Phase III standard are provided and discussed in Section 3.2.

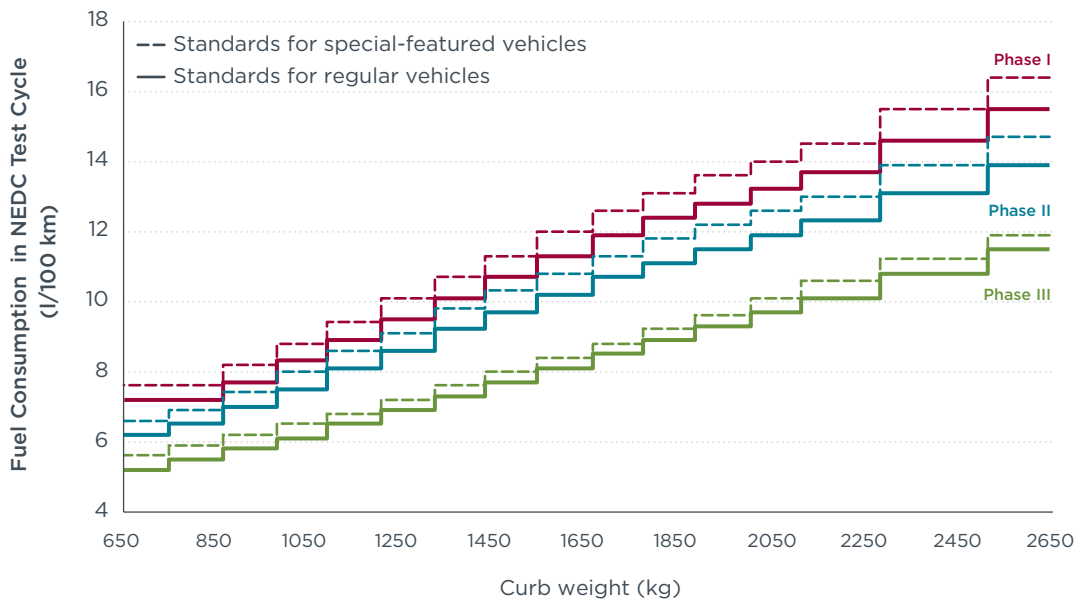


Figure 1. China's Phase I/II and III fuel consumption standards

Now, regulatory agencies in China are developing the next phase of fuel consumption regulation for 2020, with a preliminary target of 5 L/100 km fleet-average fuel consumption for new passenger cars (SC, 2012)—this corresponds to about a 36% reduction from the 2010 base level. To achieve this target, regulators are looking at feasible technologies for vehicle fuel efficiency improvement as well as their cost-effectiveness. Existing powertrain efficiency technologies, such as gasoline direct injection, turbocharging, and high gear-count transmission, still hold the most promise to reduce fuel consumption and remain the most cost-effective options in the 2020 time frame. These technologies, combined with steady improvements in reducing engine friction, aerodynamic drag, and tire rolling resistance, may realize up to 30% efficiency improvement (rough estimate using EPA's analysis, Table 1). Additional fuel reduction requirements will be met with more expensive technology options, such as hybridization, partial or full electrification. The incremental costs of these technologies are in the magnitude of at least several thousand US dollars, according to EPA's estimates (Table 1).

¹ Corporate average fuel consumption is the sales-weighted average fuel consumption of each manufacturer's models.

Table 1. GHG and efficiency technologies considered in the US, their efficiency benefits and costs (Summarized from US EPA 2010)

Technology	Fuel Use Reduction (% from baseline vehicle) ^[1]		2017 Total Cost for small car ^[2]	2025 Total Cost for small car
	Small car	Large car	2010\$	2010\$
Engine technology				
Advanced engine friction reduction	3.5	4.8	97	93
Cylinder deactivation	n.a.	6.5	196	160
Variable valve timing and lift	5.1	7	244	200
Turbocharged gasoline direct injection (TRBDS+SGDI)	12.5-18.5	15.5-22.5	704	563
Cooled exhaust gas recirculation + TRBDS+SGDI	3.6	3.6	305	249
Advanced diesel engine (T2B2 emissions level)	19.5	22.1	2965	2420
Transmission technology				
Advanced aggressive shift logic	5.2	7	34	27
High efficiency gearbox	4.8	5.3	251	202
6-speed automatic (from base 4AT)	3.1	3.9	-9	-8
8-speed dry DCT (from base 4AT)	11.1	13.1	80	66
Hybrid and battery electric technology				
12V start-stop	1.8	2.4	401	308
HV mild hybrid	7.4	7.2	3170	2273
Power split HEV	19	36	4483	3406
Two-mode hybrid drivetrain	23	28	7099	4722
Plug-in hybrid electric vehicle, 40-mile range	63	63	14401 ^[3]	8626
Full electric vehicle (EV), 100-mile range	100	100	17837 ^[3]	9676
Accessory technology				
Electric power steering	1.5	1.1	109	92
Improved high efficiency alternator (42 v)	3.3	2.5	143	120
Aero drag reduction (20% on cars)	4.7	4.7	74	71
Low-rolling-resistance tires (20% on cars)	3.9	3.9	73	44
Mass reduction 10-20% ^[4]	5-10%	5-10%	149-668	120-526

Notes:

[1] Source of benefit: EPA, 2012b. The benefits are incremental to base vehicle (2010 baseline).

[2] Source of cost: EPA, 2012b. The costs are total cost for small cars, consisting of direct (or material, manufacturing and labor costs) and indirect costs (R&D, learning, manufacturer markup, or costs related to corporation operation and selling); costs are normalized to 2010 dollars.

[3] Costs include battery and non-battery costs only; they do not include charger and charger labor cost.

 [4] Reductions did not count benefits from improved integrated design such as engine downsizing. For small amount of mass reduction (less than 5% for example), no engine downsizing is applied; therefore CO₂/fuel reduction is low (about a magnitude of 3%). But for greater mass reduction, it usually happens together with redesign; therefore, the overall benefits are much larger than the 5-10% estimates in the table.

Compared with these advanced battery technologies, vehicle mass reduction technologies are much more cost-effective. Vehicle mass is closely correlated to the amount of energy that propels the vehicle. Reducing vehicle mass without changing other functionalities of a vehicle therefore becomes an effective means of reducing energy consumption. EPA, in its technical supporting document for the MY 2017-2025 light-duty vehicle GHG emissions final rule, estimates that 10-20% mass reduction can lead to 5-10% fuel consumption benefit, and the associated cost will be about \$150-\$670 depending on vehicle size (Table 1). However, these estimates, done in 2010, did not take into account several important vehicle lightweighting studies done more recently. These studies suggests that nearly 20% mass reduction can be achieved with zero direct manufacturing cost or even with a small margin of net saving in the 2020 time frame, if accounting for the secondary or synergistic weight reduction effect (FEV, 2013; Lotus Engineering, 2012; ICCT, 2013).

The past and present Chinese fuel consumption standards are indexed to vehicle curb weight.² Fuel consumption standards indexed to vehicle mass reduce the fuel consumption target value with decreasing vehicle mass. Such weight-based standards discount the benefit of vehicle mass reduction because manufacturers that produce lighter vehicles will face more stringent targets. The impact of these two distinct standard designs on vehicle lightweighting is illustrated in Figure 2.

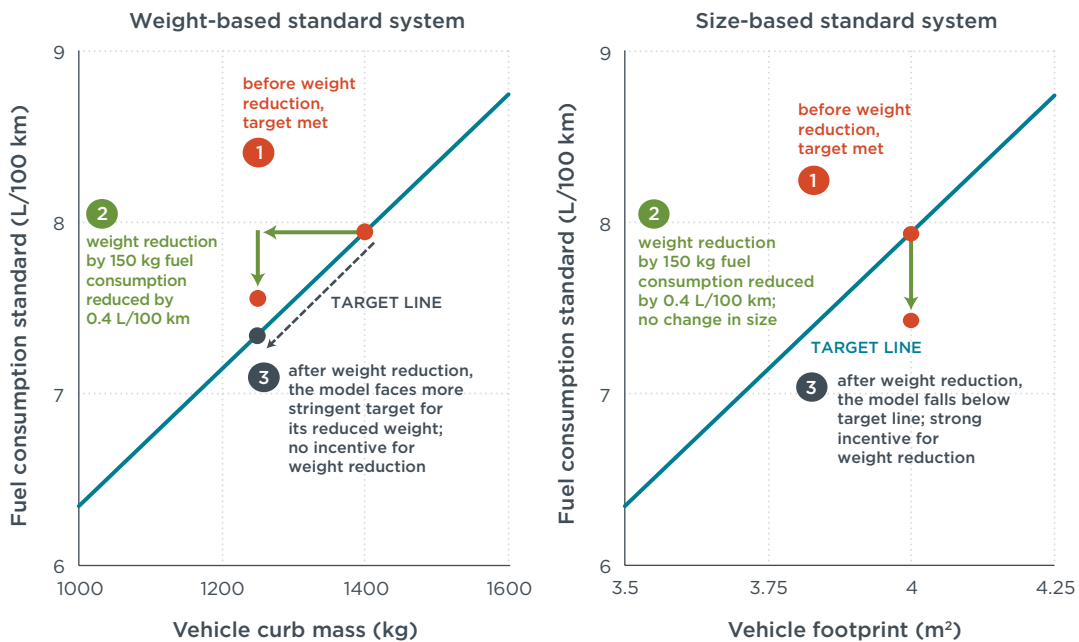


Figure 2. Illustration of different impact on vehicle lightweighting under weight- and size-based fuel efficiency standard systems

Among a few reasonable physical attributes, vehicle footprint³ (alternatively defined as vehicle size) has been recognized as an alternative to weight in designing fuel efficiency

2 Curb mass defined here is the total weight of a vehicle with standard equipment, including coolant (if necessary), lubricant, glass cleanser, a tank of oil (at least 90% of designed volume), a spare tire, fire extinguisher, standard assembly, anchor block, and standard toolbox (GB/T 3730.2-1996).
 3 The footprint is the distance between the tires of a vehicle (wheel base times track width).

standards. Vehicle size is less correlated to vehicle fuel use and is one of the most valued utilities to consumers.

Thanks to the rapid development of lightweight materials and corresponding vehicle redesigning, there are numerous technology options that can reduce vehicle mass, and therefore fuel consumption, without affecting vehicle size and other performance parameters. Lightweighting will be a vital option globally and the Chinese fuel consumption standard system should anticipate this trend by allowing it as a vital option.

The motivation of this paper is to explore how China can shift to a size-based standard, which has the potential to remove the regulatory obstacles for mass reduction technology deployment in the country. We construct alternative footprint-based fuel consumption standards for China in 2015 and 2020 and analyze the impact on manufacturers' compliance burden and competitiveness, compared with the existing weight category-based standard and a slightly improved linear weight-based standard.

This paper consists of four parts. Section 2 provides the background of this study, including a brief evaluation of different parameters for indexing vehicle fuel efficiency standards, a review of the current vehicle efficiency standard design elements in regions with such regulations, and an introduction to the development of vehicle mass reduction technologies in China. Section 3 compares the compliance burdens on major car manufacturers, under two hypothetical standard designs and the existing Phase III standards, to meet China's 2015 and 2020 fleet fuel consumption targets. The paper ends with a short conclusion.

2 BACKGROUND

This section briefly evaluates various attributes for determining vehicle fuel efficiency standards, reviews regulatory design structures of light-duty vehicle efficiency or GHG emissions standards around the world, analyzes the current vehicle weight and size relation in the Chinese market, discusses vehicle mass reduction technologies, and provides a snapshot of vehicle mass reduction technology applications and future plans of Chinese manufacturers.

2.1 VEHICLE ATTRIBUTES FOR REGULATORY DESIGN

Table 2 compares regulatory attributes and other key design elements of light-duty vehicle efficiency/GHG regulatory standard in countries that have implemented such standards. Among many possible vehicle parameters, mass and size are the most commonly considered.

Table 2. Fuel efficiency and GHG standards in major auto markets

Country/ Region	Attribute		Form			Categories, classes, other provisions
	Weight	Footprint	Class	Continuous	Bins	
European Union [#]	X			X		Eco-innovations, super-credits
United States		X	X	X		2WD, AC credit, FFV/E85, alternative fuels
Japan	X				X	Averaging within bins
China	X		X		X	Transmission, per-vehicle limits à corporate average
Canada		X	X	X		AC credits, alternative fuels
South Korea [*]	X			X		Eco-innovations
Mexico		X	X	X		
India	X			X		

[#] CO₂ standards complemented by air conditioning, tire pressure monitoring, gear-shift indicators, etc.

^{*} FE/CO₂ standards include consideration for tire pressure monitoring, gearshift indicators

Another ICCT working paper (Mock, 2011) analyzed a comprehensive list of vehicle parameters (such as payload, curb weight, footprint, and pan area) that can be used to index fuel consumption standards. Table 3 summarizes the pros and cons of each. When comparing these parameters, we mainly looked at their impact on 1) the diversity of automobile manufacturers to ensure a competitively neutral and socially equitable market and avoid unjustified distortion of competition between them; 2) the robustness of the standard to avoid any perverse effects (i.e., gaming); 3) the flexibility of technological options so as to keep as many technologies open to fuel efficiency improvement; 4) the representativeness of the majority of consumers and social equity; 5) the comprehensiveness of the standard to improve fuel efficiency or reduce GHGs emission without compromising safety; and 6) the practicability of regulation design.

Vehicle efficiency standard design can be as simple and straightforward as a flat target for the entire fleet, as with the US CAFE standard for pre-model-year 2011 cars⁴. A flat standard is straightforward and provides adequate technology flexibility, but it can disturb the competitive balance among manufacturers because it is more expensive and difficult for manufacturers of larger vehicles to meet the target than it is for those of smaller vehicles (EPA/NHTSA, 2010). To reduce competitive impact, regulators around the world have considered several vehicle physical attributes to index the standards.⁵

Vehicle size, and especially footprint, is a better attribute from a regulatory perspective because it is less susceptible to gaming and maintains technology neutrality. Compared to vehicle weight, footprint is more integral to a vehicle’s design because it is dictated by the vehicle platform, which cannot be altered easily between model years (Ferguson et al, 2007, NHTSA 2005). Furthermore, vehicle size is not as strongly correlated to fuel efficiency as mass. Footprint-based standards fully encourage mass reduction as a technology option to reduce vehicle energy consumption and therefore decrease manufacturers’ compliance cost, while weight-based systems reduce the incentives for adopting mass reduction. In addition, vehicle footprint is more visible than weight to the customer. Under a weight-based standard, manufacturers can increase weight and reduce the stringency of the target value without customers being aware of the weight increase, while size increases would be immediately obvious to customers who want better fuel economy. Admittedly, there are other factors beyond standard compliance that manufacturers use to make decisions on vehicle weight change.

Table 3. Assessment of vehicle physical parameters for standard design (Mock, 2011)

	Diversity competitively neutral, vertical spread	Robustness avoids perverse effects (gaming)	Flexibility no discrimination among technologies	Representativeness proxy for utility, socially equitable	Comprehensiveness avoid adverse effects, safety	Practicability data, continuous, definition, complexity
Flat standard	-	++	++	--	●	++
Curb weight	+	-	-	-	●	+
Payload	+	--	-	-	●	+
Gross weight	+	--	-	--	●	+
Footprint	++	+	+	●	++	+
Pan area	++	-	+	+	+	●
Engine power	+	--	-	-	●	+
Displacement	+	--	-	-	●	-

Note: Index parameter: Meets criterion substantially (++)/meets criterion (+)/does not affect criterion (●)/does not meet criterion in most cases (-)/does not meet criterion at all (--)

4 The car CAFE standard was established by Congress in Title V of the Motor Vehicle Information and Cost Savings Act in 1975, the standard for cars had been 27.5 mpg since 1990. <http://www.dieselnet.com/standards/us/fe.php>

5 Europe, China, Japan and South Korea have regulatory standards that use vehicle mass, while the U.S. and Canada use vehicle size.

2.2 OVERVIEW OF VEHICLE MASS REDUCTION TECHNOLOGIES

A critical distinction between weight-based standard and footprint-based standard is their impact on the development of lightweight vehicles. Mass reduction is one of the most promising long-term approaches considered by the US EPA/NHTSA to realize significant fuel consumption reduction at a reasonable cost. The Regulatory Impact Analysis (2012b) conducted by EPA conservatively estimated 5% mass reduction for cars and 7% for trucks in 2021, and 6% and 10%, respectively, in 2025.

In general, technologies for mass reduction include advanced material substitution (e.g., high-strength steel, aluminum, magnesium, and plastics/composites), and integrated vehicle redesign (e.g., parts integration and holistic optimization).⁶ Additional mass reduction can be achieved by incorporating the effects of engine downsizing and associated secondary mass reduction effects.

More recent research indicates that greater degree of mass reduction is possible at even lower costs assumed by EPA (Lotus, 2012; FEV, 2012 and 2013; NHTSA, 2012; WAS, 2011)⁷. For example, an International Energy Agency (IEA) study (2012) suggests an estimated 14% potential of fuel use reduction through combination of lightweight components and design. A recent ICCT study (Meszler, 2013) of EU mass reduction cost shows that the first 20% mass reduction achieves cost savings of 1-4 euros per kg, which is far less than the cost estimated by EPA. Thus, mass reduction can play a big role in fuel economy improvement in a cost-effective manner.

Many world leading auto manufacturers have plans for vehicle mass reduction as a strategy to meet the increasingly tightened regulatory standards for vehicle efficiency or GHG emissions not only in the US, but also in regions using weight-based standard, such as EU and Japan. Ford and Chrysler have announced vehicle mass reduction as part of their commercial deployment of efficiency technology by model year 2016 (Lutsey, 2012). Nissan, Toyota, and Mazda have also made commitments to certain mass reduction in individual or all vehicle models (Lutsey, 2010). More recently, GM asserts that it will achieve up to 15% mass reduction of its new models by 2016⁸ and has already begun to put its 2014 full-size pickups on a “diet” through redesigning to achieve better fuel economy.⁹ Table 4 also shows some of the recent development in vehicle model mass reduction using advanced materials and parts redesign.

6 Source: US EPA, NHTSA, CARB 2011-2012 assessments for fuel economy and CO₂ standards

7 In the four new major studies, NHTSA EDAG study of 2011 Honda Accord shows up to 22% mass reduction at incremental \$319 per vehicle cost increase; WorldAutoSteel EDAG study of small car indicates up to 15% mass reduction with no net vehicle cost increase; EPA FEV study of 2010 Toyota Venza shows up to 18% mass reduction at net \$148 incremental vehicle cost saving; CARB Lotus study of 2009 Venza indicates up to 32% mass reduction at up to \$419 per vehicle cost savings. FEV (2013) also estimated additional cost of attaining a CO₂ target of 95 g/km by 2020 in EU for passenger cars will reduce from 1,000 euros per vehicle (without mass reduction) to 600 euros.

8 http://www.gm.com/article.content_pages_news_us_en_2013_mar_0306-akerson.-content-gmcom-home-vision-environment1.html

9 A redesign of the 2014 Silverado may drop as much as 500 pounds: <http://www.caranddriver.com/features/2014-chevrolet-silverado-gmc-sierra-future-cars>

Table 4. Recent vehicle model development with mass reduction technology

Model	Mass Reduction	Fuel economy gain	Technology
2014 Cadillac CTS ¹	111 kg, 6.3% compared to its predecessor	N/A	Aluminum and adhesive
2014 Audi Q7 ²	363 kg, 14.5% compared to its predecessor	N/A	Aluminum body plates
2011 Porsche Cayenne ³	181 kg, 8%, compared to its predecessor	3 mpg (from 19 mpg to 16)	High-strength steel throughout, aluminium and high-strength steel chassis parts
2014 BMW i3 EV ⁴	227 kg, 16.6%, compared to steel structure	N/A	Carbon-fiber inner body, aluminium rolling chassis, polymer plastic outer body panel

1 <http://media.gm.com/content/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2013/May/0509-cadillac-cts.html>

2 <http://www.worldcarfans.com/113051457640/next-gen-audi-q7-to-lose-about-800-lbs---report>

3 Lutsey, 2010.

4 <http://www.greencarcongress.com/2013/07/bmw-i3-20130710.html>

2.3 MASS REDUCTION AND VEHICLE SAFETY

As an opposite of public concern, heavier vehicle is not necessarily safer. Larger vehicles are safer for their occupants, but it is their size, rather than weight, that makes cars safer (Auken & Zellner, 2004). Lightweighting does not necessarily sacrifice safety. Based on existed studies, NHTSA believes that reducing vehicle weight while maintaining track width and wheelbase would bring significant safety benefits.

Among many factors that decide vehicle safety, vehicle design (e.g., geometrical structure) will dominate instead of size or weight (German, 2011). In the long term, computer simulations will allow manufacturers to reduce weight without affecting safety or ride quality. High-strength steel and aluminum are both stiffer than conventional steel, so with proper design (rapidly being improved due to improvements in computer simulations), safety and ride (and handling) will be improved as well. The US agencies projected that manufacturers would mainly accomplish mass reduction through strategies to meet safety concern, such as material substitution, smart design, reduced powertrain requirements, and mass compounding (CFR, 2010).

2.4 VEHICLE WEIGHT AND SIZE CORRELATION IN CHINA

In general, vehicle curb weight and footprint are highly correlated in China (Figure 3). However, vehicle models competing in the same market segment of similar footprint levels and horsepower can have curb weight differences of as much as a few hundred kilograms. Figure 4 shows the curb weight range of real car models controlled by market segment, footprint ranges and horsepower. At the manufacturer level, although manufacturers producing larger vehicles tend to have heavier corporate curb weight, it is also observed from Figure 4 that corporate fleets at very close footprint levels can have great differences in corporate curb weight. The various degrees of weight differences, illustrated by Figure 3 to 5, indicate that Chinese manufacturers may already be adopting to various degrees mass reduction technologies or technologies that indirectly result in reduced vehicle weight.

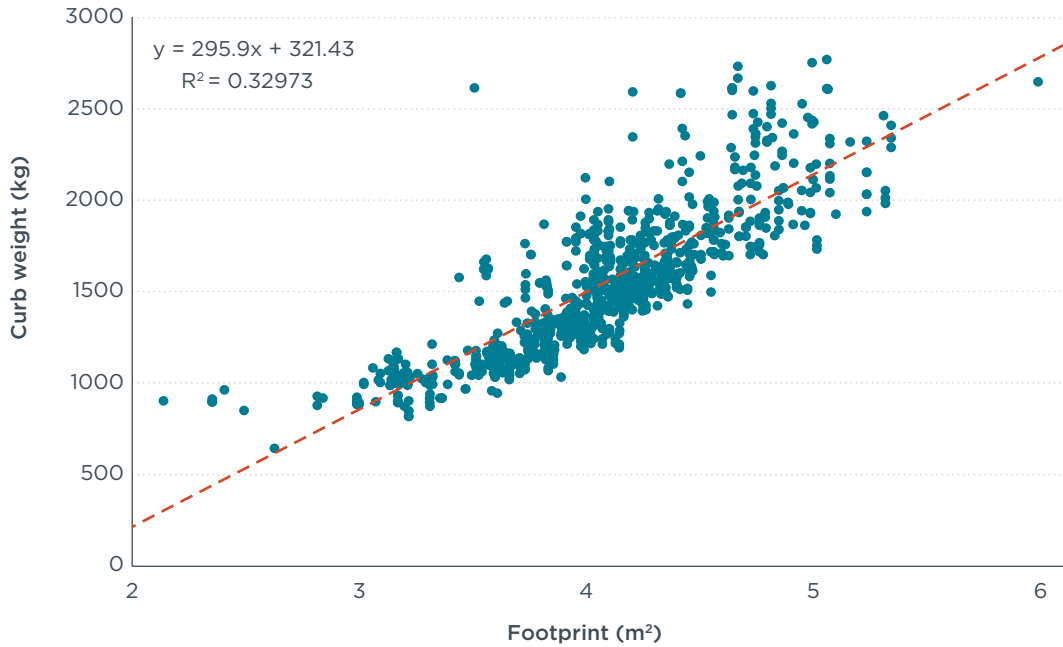


Figure 3. Correlation of vehicle curb weight and footprint in the current Chinese passenger car market

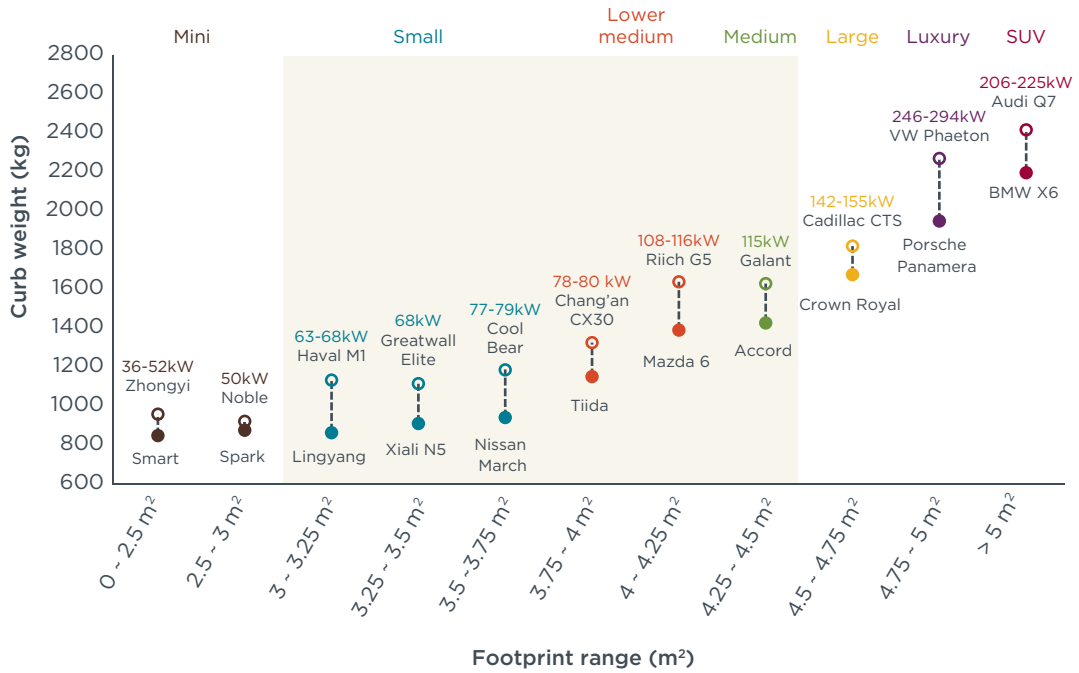


Figure 4. Range of curb weight of vehicles with similar horsepower, by footprint bins and market segment in China

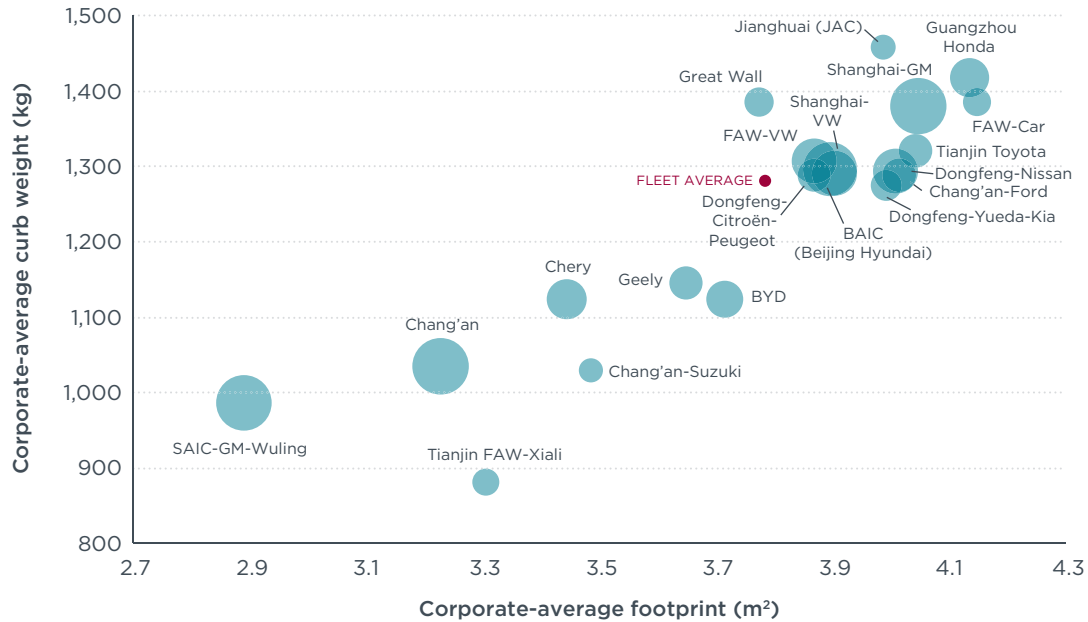


Figure 5. Relation of corporate footprint and curb weight by major manufacturers in China

2.5 MASS REDUCTION TECHNOLOGY APPLICATIONS AND FUTURE PLANS IN CHINA

Our literature review showed that Chinese manufacturers have increasingly adopted mass reduction technologies over the past decade. High-strength steel, aluminum, magnesium, and plastics and polymer composites have been increasingly used on vehicles to replace traditional material components. For example, FAW-Magotan adopts 74% HSS/AHSS (>180 MPa) of its high-strength body (HSB) structure,¹⁰ Dongfeng-Nissan Bluebird, Yiida, and FAW-Audi A6L have used more than 100 kg of aluminum per car, FAW-Audi A6 use 48 kg magnesium per car and Chang'an adopt 20.1 kg magnesium to CV11 (DRC, 2012). However, the overall extent of mass reduction employed by Chinese manufacturers appears to be lower than their US competitors. Very few Chinese manufacturers have specific plans for mass reduction. Chang'an clearly set its goal in 2011 of a 10% mass reduction by 2020 (SAE & Alliance, 2011).

There are several possible reasons for Chinese OEMs' conservative mass reduction plans. Some obstacles may be technical, such as lack of supply of advanced lightweight materials for automotive application and limited technical capacity for vehicle designing and manufacturing (such as tailor-welded blanks) among OEMs (Liu, 2012).

Regulatory design obviously affects carmakers' decision-making on vehicle mass reduction technology deployment. China's current weight-based vehicle fuel consumption standards provide little incentive for automakers to research and deploy emerging mass-reduction technologies in their new model designs. In the context of developing the next phase of vehicle fuel efficiency standards, the structure of the standards should give manufacturers a full incentive to include mass reduction in the future fuel efficiency technology portfolio.

¹⁰ <http://auto.163.com/11/0817/13/7BLMF8RF000841JS.html>

3 ALTERNATIVE STANDARD DESIGNS AND IMPACT

This section probes two alternative standard designs—a US-style footprint-based standard curve, and an EU-styled continuous weight-based standard curve—for new passenger car fuel consumption in China, and analyzes their impact on manufacturers. To illustrate the differences in manufacturers’ compliance burden across various standard designs, we compare the percentage improvement rates required to meet China’s 2015 and 2020 fleet-average targets under the alternative standard structures with those under the current standard structure. Note that this paper does not measure the compliance burden in the dollar costs to manufacturers.

Our analysis is based on China’s 2010 passenger car data.¹¹ For most of the analysis in this section, we focus on the top 20 auto manufacturers in terms of their market share in 2010, including both domestic (independent and joint venture) and foreign manufacturers of import cars. Altogether they represent about 83% of the market (Figure 6).

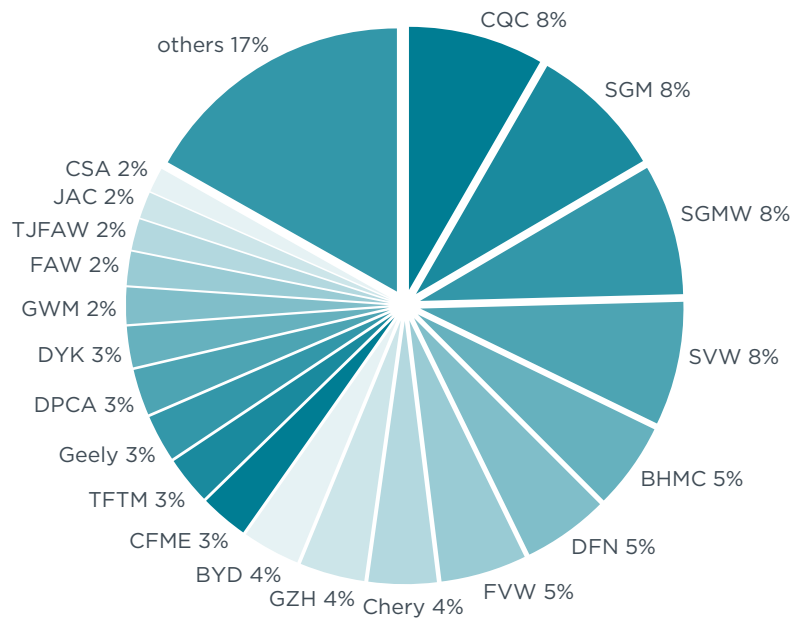


Figure 6. Market distributions of top 20 OEMs . (See appendix for explanation of acronyms.)

¹¹ The data used in this paper are 2010 passenger car sale statistics for China, provided by Segment Y Automotive Intelligence (www.segmenty.com), an India-based company with a focus on the Asian automotive market. Other vehicle information, such as curb weight, footprint, and fuel consumption, come from the Ministry of Industry and Information Technology (MIIT) website. The data contains 55 domestic manufacturers (i.e., OEMs) and 19 import brands: CQC-Chang’an, SGM-Shanghai GM, SGMW-GM Wuling, SVW-Shanghai-VW, BHMC-Beijing Hyundai, DFN-Dongfeng-Nissan, FVW-FAW-VW, GZH-Guangzhou Honda, CFME-Chang’an Ford, TFTM-Tianjin Toyota, DPCA-Dongfeng-Citroën-Peugeot, DYK-Dongfeng-Yueda-Kia, GWM-Great Wall, TJFAW-FAW-Xiali, JAC-Jianghuai, and CSA-Chang’an-Suzuki.

Table 5 shows the some key statistics of the top 20 manufacturers relevant to our analysis, including their market size (sales volume in 2010), sales-weighted average vehicle curb weight, footprint, and fuel consumption. All data in Table 5 are color-coded by their absolute value—the greater the values, the cooler the colors that are applied. The color-coding enables easy evaluation and visualization of fleet efficiency of the manufacturers.

It is important to distinguish between fleets with the lowest fuel consumption levels in absolute terms and relatively efficient fleets. A few manufacturers shown in Table 5 focus on the smallest car segments and also maintain the lowest corporate fuel consumption rates. For example, Tianjin-FAW-Xiali, Chery, and Chang'an-Suzuki produce the lightest and smallest vehicles in the Chinese passenger car market, and their corporate-average fuel consumption levels are also among the lowest of the entire passenger car fleet at 6.5, 6.8, and 6.9 L/100 km, respectively. For these manufacturers, their vehicle weight, size, and fuel consumption data cells all fall into the same or similar/neighboring color tones.

When a manufacturer's fuel consumption data cell is in warmer tones than its vehicle weight and size data cells, it means the corporate fleet is relatively efficient for its vehicle weight and size class, such as the cases for FAW-VW and BYD. And the opposite indicates that the corporate fleet is less efficient for its class, e.g. Shanghai-GM-Wuling, Chang'an, and Dongfeng-Citroen-Peugeot. Although it is not always the case, relative fleet efficiency is a better indicator than the absolute corporate fuel consumption levels for the adoption of advanced technologies. A 2012 ICCT report (He and Tu, 2012) found that FAW-VW had the highest application rates of major efficiency technologies including boosted gasoline direct injection, continuous variable valve lift, and dual clutch transmission, among the top 20 car manufacturers; while the two minivan producers Shanghai-GM-Wuling and Chang'an have lagged behind in advanced technology adoption. These findings are consistent with the relative fleet efficiency evaluation mentioned above.

Table 5. Fleet characteristics of 2010 Chinese new passenger cars, by manufacturer

	Sales	Curb weight (kg)	Footprint (m ²)	Fuel consumption L/100 km
Chang'an	1,095,380	1,034	3.2	7.4
Shanghai-GM	1,087,470	1,380	4.0	7.8
SAIC-GM-Wuling	1,057,803	985	2.9	7.8
Shanghai-VW	1,002,094	1,295	3.9	7.9
BAIC (Beijing Hyundai)	699,666	1,290	3.9	7.5
Dongfeng-Nissan	694,873	1,294	4.0	7.8
FAW-VW	694,514	1,306	3.9	7.3
Chery	548,994	1,122	3.4	6.8
Guangzhou Honda	525,963	1,417	4.1	8.2
BYD	468,235	1,123	3.7	6.6
Chang'an-Ford	389,352	1,288	4.0	7.5
Tianjin Toyota	386,431	1,319	4.0	7.4
Geely	378,637	1,145	3.6	7.5
Dongfeng-Citroën-Peugeot	373,359	1,288	3.9	8.1
Dongfeng-Yueda-Kia	329,562	1,275	4.0	7.4
Great Wall	294,402	1,384	3.8	7.9
FAW-Car	270,881	1,385	4.1	8.1
Tianjin FAW-Xiali	250,194	880	3.3	6.5
Jianghuai (JAC)	213,433	1,457	4.0	8.4
Chang'an-Suzuki	200,013	1,029	3.5	6.9
Average market	13,732,798	1,279	3.8	7.8

3.1 ASSUMPTIONS AND PRINCIPLES FOR DEVELOPING ALTERNATIVE STANDARD CURVES

There are a few essential elements when constructing a standard curve.

Form of curve:

As mentioned earlier, vehicle efficiency or GHG emissions standards usually index to vehicle attributes. The standard curve can be step-wise or continuous. A step-wise standard curve may create incentives to “game” the indexed attribute. For example, a weight-bin-based standard creates an incentive for pushing the weight of a vehicle model towards the upper limit of each weight class (see 3.3 for the case in China). Continuous standard curves have the advantage in preventing such gaming.

For simplicity, most existing continuous efficiency standards are linear (or at least linear for the majority of the fleet). A continuous standard curve does not have to be linear—a logistical curve or exponential curves (Figure 7) yield similar benefits. In general,

the form/shape of a standard curve should be based on the fit of correlation between vehicle efficiency (or the regulatory target metric) and the vehicle attribute. However, regulators may also “manipulate” a standard curve for specific consideration of certain vehicles. For example, a linear weight-based standard curve means a constant penalty in efficiency target for a vehicle weight increase, and an exponential standard curve (for example) means an increased penalty.

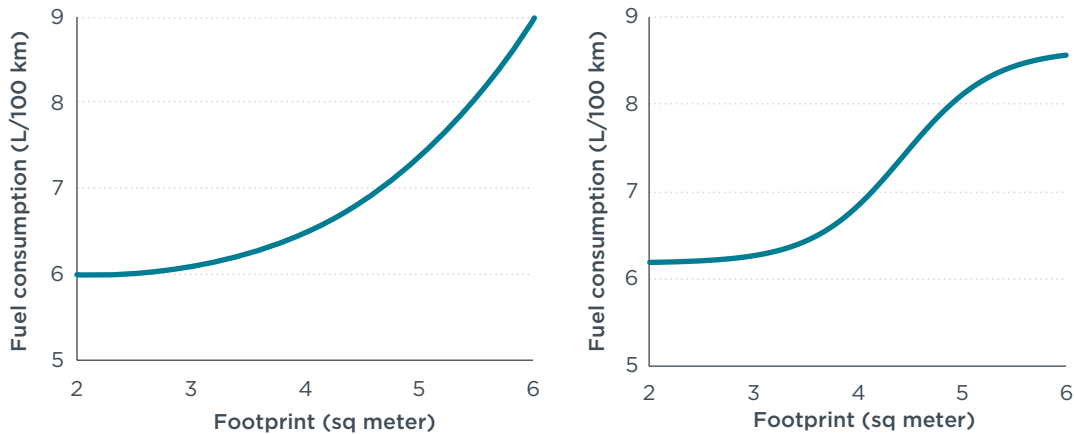


Figure 7. Possible alternative fuel consumption standard curves

Slope:

The slope of a standard curve has a direct impact on manufacturers’ compliance requirements and competitiveness under any attribute-based system. Under linear standard curves (for simplicity), steep lines indicate easier targets for vehicles of greater selected attribute and penalize vehicles of smaller selected attribute with tougher targets. This affects standards for both vehicle weight-based and size-based standards in our context.

In general, the slope of a standard curve should also be based on the existing correlation between target metric and chosen vehicle attribute. However, then regulators need to carefully determine the slope for the standard curve so that an autonomous increase of the attribute concerned can be somehow prevented.

For example, regulators in the EU, when developing their 2015 CO₂ standard curve, adopted a flatter slope than the market trend line. They analyzed a range of slopes, from 20% to 100%. The percentage value placed before a slope indicates the degree of rotation from an original curve to a target curve. A 100% slope means adjusting the current market trend line by the same desired percentage of reduction on each index parameter level to derive the target curve, with no tilting. Studies show that generally, each 10% increase in vehicle weight results in about a 6.5% increase in fuel consumption (EPA/NHTSA, 2009). EU regulators concluded that a 60% slope may effectively prevent a trend towards fleet up-weighting.¹²

Of course, as stated earlier, a weight-based standard has the fundamental setback of discouraging lightweighting. But this should not be mixed up with the slope discussion

¹² The detailed methodology is described in Fergusson, M., Smokers, R., et al. (2008): “Footprint as utility parameter: A technical assessment of the possibility of using footprint as the utility parameter for regulating passenger car CO₂ emissions in the EU.”

here. Similarly, a size-based standard should be flatter than the natural market trend of size-efficiency correlation to effectively prevent upsizing.

Center of gravity:

The center of gravity of a linear standard curve is the pivot point around which the curve rotates, and it is usually set as the fleet-average efficiency target at the fleet-average attribute level of a target year. The known fleet-average attribute, often based on current fleet statistics, may change in a future target year. Therefore, regulators may incorporate certain mechanism to adjust the center of gravity so that even though the fleet-average attribute changes, the target remains the same.

For example, the EU took account of autonomous mass increase (AMI) when constructing its weight-based standard curve. In the EU's current standard, a 0.82% AMI was incorporated as an estimation for the future fleet.

Caps:

Regulators may set caps (or constant target limits) for certain vehicles, while the majority of the fleet remains subject to a linear standard curve. For example, the US sets both upper and lower limits for the largest and smallest vehicles under the footprint-based fuel economy and GHG emissions standards. In particular, by capping the GHG emissions targets for some of the largest light-duty vehicles in the US market, the standard strongly penalizes large-sized vehicles and upsizing. On the other hand, the smallest vehicles will face less stringent targets, based on feasibility and cost assessment.

Below are our assumptions and principles for developing the alternative standard curves. Since the main purpose of this paper is to compare the compliance burden between weight-based and footprint-based standards, the construction of **hypothetical** curves is simplified by assuming that the current fleet structure remains valid for fleet targets in 2015 and 2020. In particular, we assume that:

- I. The fleet mix remains constant, with no fleet weight increase and upsizing between the baseline year (2010) and the target years (2015 and 2020).
We noticed that the average new-car curb weight has been growing in the past few years.¹³ But considering the Chinese government's intention to downsize the fleet, for instance by encouraging the purchase of small cars under 1.6 L, the construction of the hypothetical curve in this paper assume does not consider AMI. Admittedly, Chinese policymakers may consider incorporating some annual mass increase based on historical data. This would result in the whole standard curve horizontally shifting to the right.
- II. There is no change in the overall ambition or stringency of China's 2015 and 2020 fleet targets—2015 and 2020 targets will remain at 6.9 L/100 km and 5 L/100 km, respectively. Thus, the center of gravity of all standard curves, which represents the fleet average target, remains constant for the same target year.
- III. The sales-weighted regression line based on binned data¹⁴ is representative of the current fleet baseline, as it gives more equal attention to all manufacturers rather

¹³ China's passenger vehicle average weight increase rate was around 0.8% from 2006 to 2010, but the number has been unstable recently. In 2009, the weight increase rate was 0.29%, while in 2010 it decreased to -1.31%.

¹⁴ To reduce the bias of the trend line, each model is rounded to small weight segments (20kg interval) or footprint segments (0.05 m² interval) to build the regression line upon sales-weighted average fuel consumption of each bin.

than emphasizing major manufacturers more heavily. Starting from the binned data trend line, a new curve is formed by shifting every point downward by a fixed percentage. For example, the 2015 standard curve is derived by shifting the 2010 baseline downward by 11.5% to reach the new center of gravity at 6.9 L/100 km, the 2015 fleet-average target.

- IV. We adopt a 60% slope¹⁵ for both the continuous weight-based standard curve and the sloping portion of the footprint-based standard curve. According to EU study (Fergusson, Smokers et al. 2008), a 60% slope for size-based fuel consumption standards is sufficient to avoid gaming. For the purpose of comparison, this slope is chosen for weight-based standards as well.
- V. The fleet target will be based on the sales-weighted average fleet weight/ footprint. The functions are

$$AVWT = \frac{\sum_1^N FC_i \times V_i}{\sum_1^N V_i} \qquad AVFP = \frac{\sum_1^N T_i \times V_i}{\sum_1^N V_i}$$

Where,

i - passenger car model

FC_i - fuel consumption of model i

V_i - sales of model i

AVWT- sales weighted average fleet weight

AVFP- sales weighted average fleet footprint

T_{CAFC} - corporate average fuel consumption target

¹⁵ An ICCT report, "Evaluation of parameter-based vehicle emissions targets in the EU: How regulatory design can help meet the 2020 CO₂ target," published in July 2011, provided general guidelines in how to develop slopes for linear continuous standard curves (Section 3.1.2). This report adopts the same guidelines, and will not repeat the detailed methodology and procedures.

3.2 COMPLIANCE BURDENS UNDER THE CURRENT STANDARD SCHEME

China's Phase III fuel consumption standard for new passenger cars is indexed to 16 curb weight bins. A manufacturer is required to meet its specific corporate-average fuel consumption target calculated by averaging the targets for each vehicle model sold by the manufacturer in a given year by its actual annual sales volume. It was estimated that if all manufacturers meet their targets, the overall fleet-average fuel consumption in 2015 will be 6.9 L/100 km (Figure 8). Figure 8 also shows a derived slope of the standard curve obtained by regressing the midpoint of each weight bin.

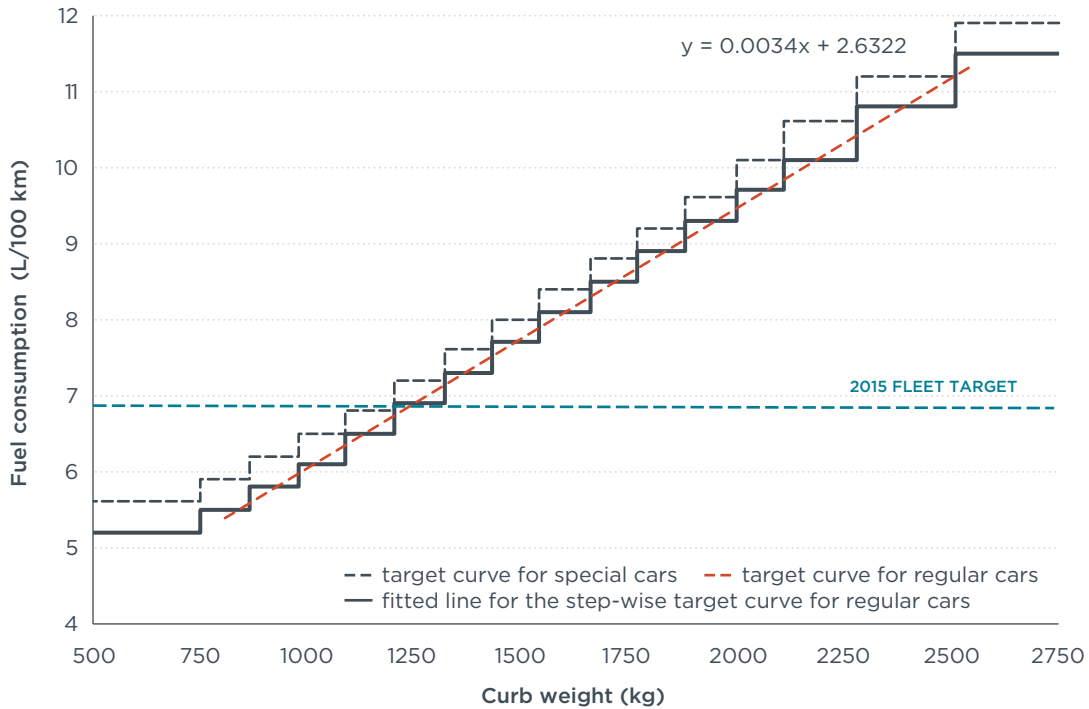


Figure 8. Illustration of Chinese Phase III fuel consumption standard for new passenger cars

However, the regulatory agency in China used part of the 2008 (or earlier) market data¹⁶ as the baseline to develop the Phase III standard for each weight bins and to estimate the 2015 fleet-average fuel consumption. Since then the market structure has changed and will continue to change in the future. In particular, the fleet-average curb weight has increased from about 1,240 kg to 1,295 kg, or 3.6%, from 2009 to 2012 (CATARC, 2013). This change had much to do with the growing demand by consumers for bigger and more luxurious vehicles. For example, from 2009 to 2012, passenger vehicles with displacement between 1.3 and 1.6 liter increase from 40.4% to 47.8% while vehicles with displacement between 1 and 1.3 liter decrease from 15.6% to 9.6% (CATARC, 2013). As a result, the assumptions used in developing the Phase III standard no longer hold, and based on the 2010 market data, even if all manufacturers are in compliance, the Phase III standard may result in achieving an average fuel consumption level of 7.2 L/100 km.¹⁷

¹⁶ *The Development Of Phase III Standard* (p. 5) stated that for developing the Phase III standard limits, CATARC surveyed 27 domestic and foreign auto manufacturers for 774 new car models available up to November 20, 2008.

¹⁷ I.e., unless China provides another incentive for OEM to implement the standards, the fleet will not achieve the 2015 goal.

Given that the primary assumption of our analysis, as well as the major goal of our report, is to guarantee that the fleet-average target of 6.9 L/100 km will be met by 2015, we had to adjust every manufacturer’s improvement rate by an additional 3.9% (6.9/7.18-1). Therefore, compliance burdens under the Chinese Phase III standard analyzed in the following part of the paper all refer to these **adjusted** Phase III standard compliance burdens. Figure 9 illustrates the required percentage reduction required to meet the specific Phase III corporate-average fuel consumption (CAFC) standard for major manufacturers.

The compliance burden in terms of percentage fuel consumption reduction rates varies greatly among the automakers. Eight manufacturers, including three Chinese independent brands—Geely, Chang’an, and Tianjin-FAW-Xiali—need to improve by more than the average rate. The two primary minivan producers, Chang’an and Wuling, both face the toughest targets. Compared to Tianjin-FAW-Xiali, independent brands BYD and Chery, which also focus on mini- to small car segments, are closer to meeting their Phase III targets.

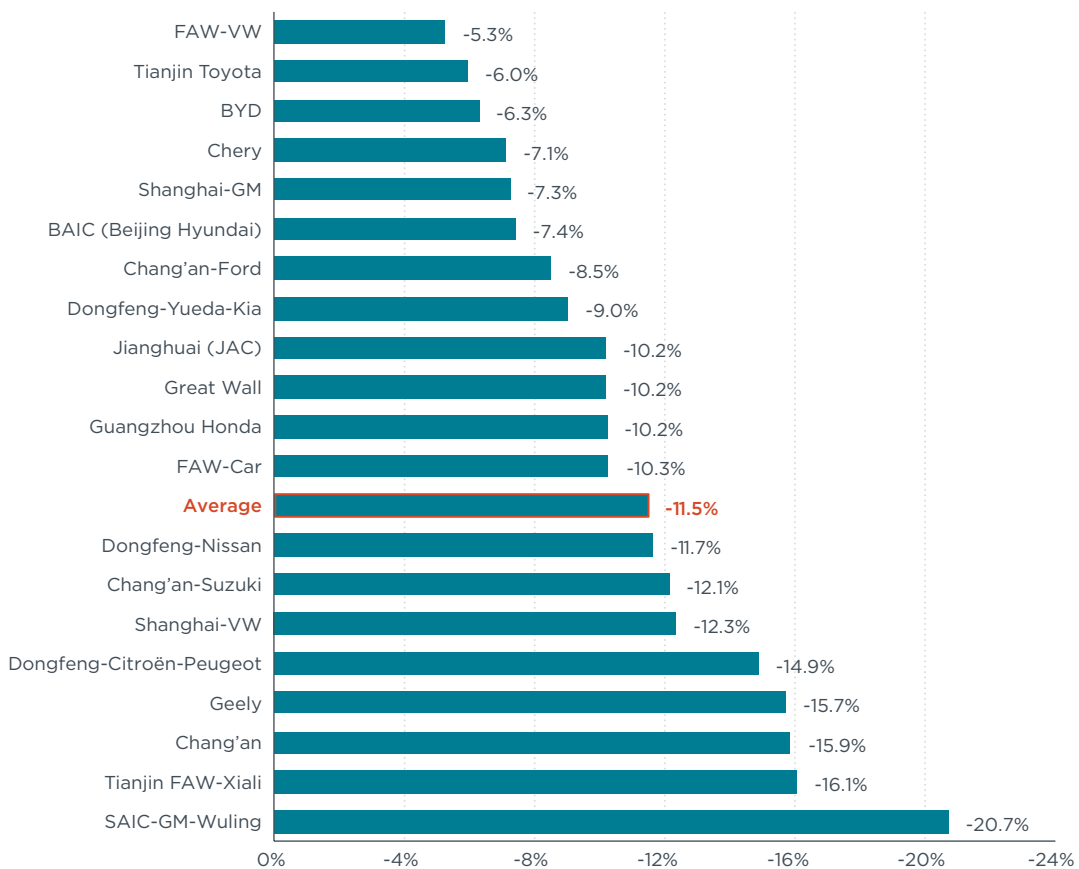


Figure 9. Percentage reduction required to meet China’s Phase III CAFC standards with projected fleet-average target of 6.9L/100 km

When expanding our analysis to all manufacturers, we observed that a few automakers have already out-performed their Phase III CAFC requirements. These are Brilliance BMW, Hawtai, and SAIC Nanjing, though their market shares are much smaller compared with those of the top 20 automakers analyzed above. The current corporate average fuel consumption rates for these manufacturers are under the Phase III requirements by 3%, 3%, and 8%, respectively.

These three automakers each have distinct reasons that allowed them to excel in reducing fuel consumption. Brilliance BMW offered high-end BMW 5 series models equipped with the most advanced eight-gear transmission and variable valve lift technologies. Hawtai and SAIC-Nanjing both had large diesel fleets and benefitted from the higher energy density of diesel fuel than gasoline in the liter-per-distance term.¹⁸ The compliant automakers all focused on larger vehicle segments, indicating that even for the heavier weight classes, the technologies are already there to meet the Phase III targets.

3.3 COMPLIANCE BURDENS UNDER A CONTINUOUS WEIGHT-BASED STANDARD

China’s current fuel consumption standards divide passenger cars into 16 classes based on their curb weight and set specific target for each class. Such bin-based systems may provide an incentive for gaming, as some manufacturers may intentionally increase the weight for vehicle models that are close to the defined weight-bin boundaries by just enough to obtain less stringent fuel consumption targets associated with the next heavier bin.

Figure 10 shows the sales distribution of vehicles by the distance of their actual curb weight from regulatory curb weight bin boundaries. It is observed that the share of vehicles weighing just above (up to 10% heavier than) each regulatory weight bin boundary is significantly higher than those of other vehicle weight levels between weight bin steps, and especially is almost twice as much as the share of vehicles weighing right below (up to 10% lighter than) or right at each bin boundary.

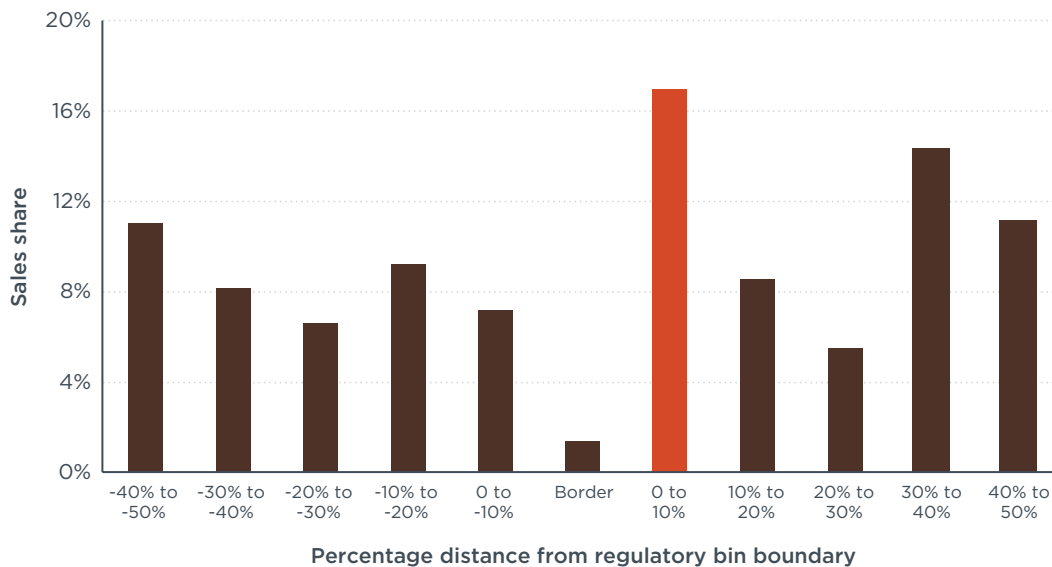


Figure 10. Distribution of new passenger car sales by curb weight, divided into 10 categories for each weight class and aggregated over all weight classes

¹⁸ In China’s Phase III and previous passenger car fuel consumption regulations, fuel consumption of diesel cars is measured in terms of diesel liter per hundred kilometers on NEDC cycle, without being converted to gasoline equivalent. This is mainly due to the tiny share of diesel vehicles in the overall fleet (less than 0.5%), so the regulators did not bother to require the conversion.

Note that according to the test protocols in China, if a manufacturer intends to move a vehicle model from a lower regulatory weight class to a higher one to gain a more lenient fuel consumption standard by slightly increasing the vehicle’s curb weight, the vehicle model will also be assigned a heavier test weight for the fuel consumption test, and thus get a higher fuel consumption test result. The rule of thumb for correlation between vehicle weight and fuel consumption is that a 10% increase in weight results in about 6.5% increase in fuel consumption (EPA/NHTSA, 2009). Therefore, theoretically manufacturers’ decisions on whether to increase the weight of a vehicle are based on how the benefit of a less stringent fuel consumption target compares to the fuel consumption penalty from the slight increase in vehicle weight. From our analysis, for most of the vehicle weight bins (especially the highest-selling ones), fuel consumption penalty from moving to the next bin will be less than the increase in the fuel consumption target. Still, there are other factors beyond standard compliance that drive manufacturers’ decisions about vehicle weight change.

Of course, conceptually the effect can be reversed, too—a vehicle model’s weight is close to the next weight bin but is assigned with a relatively stringent target compared with the lighter vehicles in the same weight bin. A continuous linear weight-based standard, similar to that adopted in the EU and South Korea, can be a substitute to China’s Phase III standard that avoids such a “corner effect.”

In this section, we construct continuous weight-based standard curves to meet China’s 2015 and 2020 fleet fuel consumption targets, using the assumptions specified in Section 3.1. We used a 60% slope based on the sales-weighted trend line of the 2010 market data between vehicle curb weight and fuel consumption ratings as the slope of the target curve. As mentioned above, the flatter curve reduces the incentive to increase vehicle weight. The equations of the target linear curves for 2015 and 2020 are shown in Figure 11.

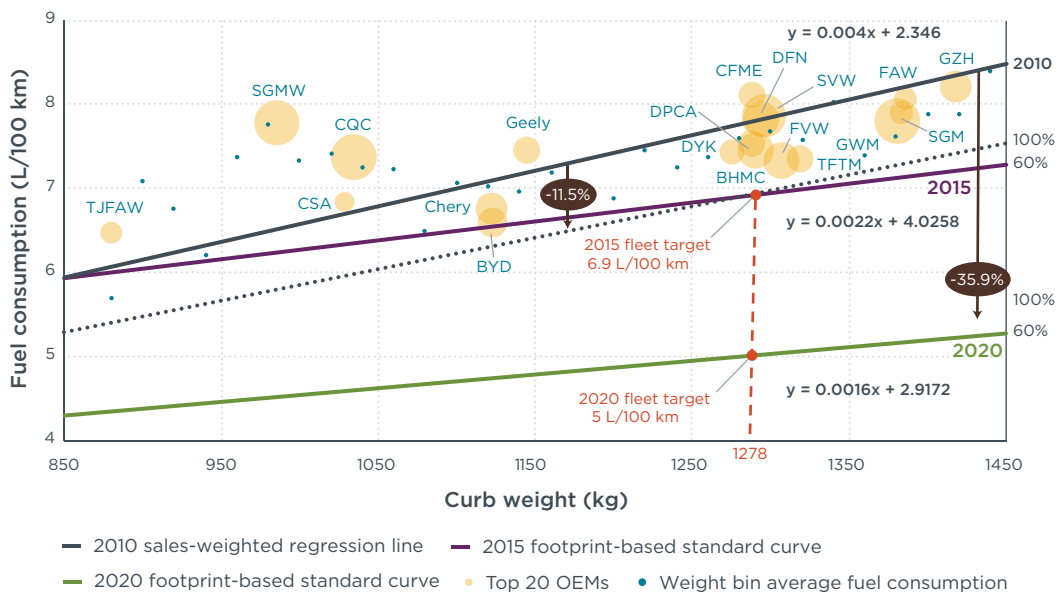


Figure 11. Continuous weight-based fuel consumption standard for 2015 and 2020

Figure 12 specifies the percentage reduction each major manufacturer will need to meet its specific weight-based CAFC targets in 2015 and 2020. BYD only needs to achieve 1% reduction in corporate fuel consumption to meet its 2015 weight-based target. Chang’an and SAIC-GM-Wuling, produce some of the lightest vehicles in the market but also have relatively inefficient fleets, and thus will have to make the most improvement. Note that all effects are dependent on our assumption of a 60% slope curve.

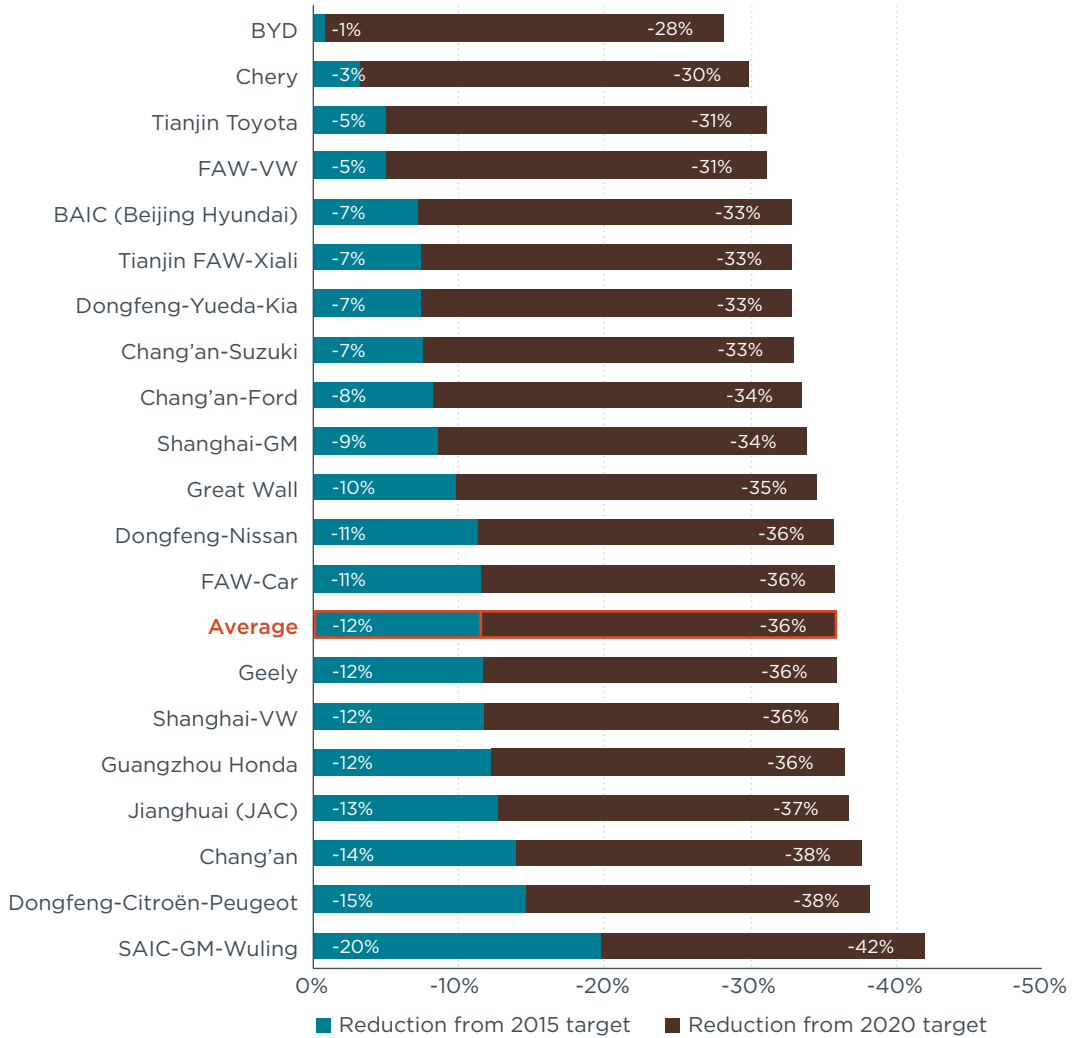


Figure 12. Comparison of OEMs target under hypothetical continuous standard and Phase III standard

3.4 COMPLIANCE BURDENS UNDER A SIZE-BASED STANDARD

The US CAFE and GHG standard curves set fixed limits at both the largest and the smallest vehicle footprint levels and distinctive target values for footprint levels in the middle. The curve’s constrained ends were intended mainly to avoid exceedingly burdensome targets for automakers focusing on niche or small car market segments, as well as to avoid undesired incentives for upsizing.

To develop US-styled footprint-based standard curves for China, we first needed to determine the points where the hypothetical standard curve becomes flat. The sales distribution by vehicle footprint (Figure 13) suggested that more than 90% of the fleet footprint falls between 3 and 4.5 m². However, two abnormal peaks existed at the smallest footprint levels (about 2.15 m² and 3.25 m², respectively). These extremely small vehicle sizes reflect a unique vehicle type in China: minivans. We overlaid the minivan footprint distribution (blue-shaded columns) on top of the rest of the fleet (brown-shaded columns) in Figure 13.

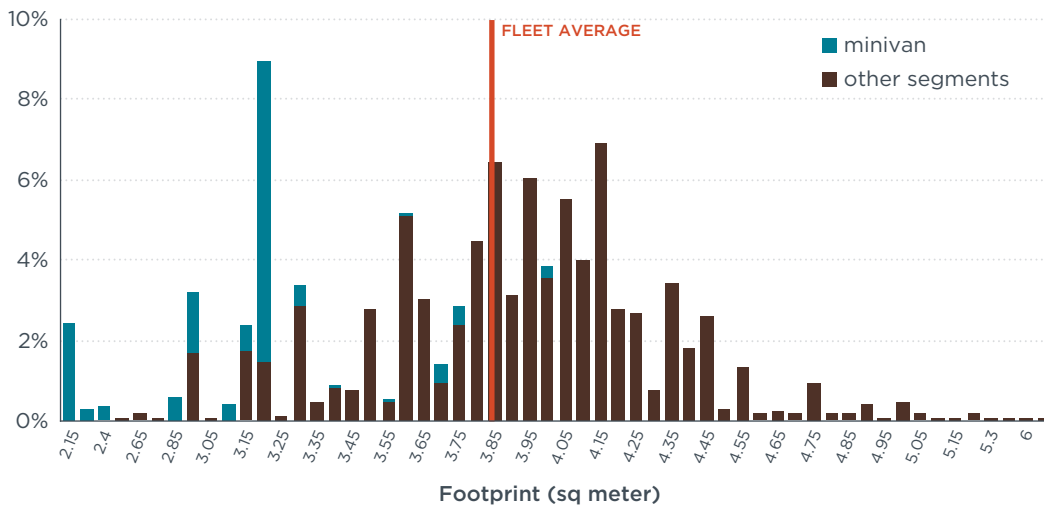


Figure 13. Sales distribution by footprint of new Chinese cars

Minivans are small, multi-function vehicles built on the minicar platform, but are narrower and taller so as to have greater interior space to carry passengers or goods. They are mainly used by rural consumers for their flexibility and extremely low price. Though minivans are small, their average fuel consumption is similar to that of a mid-sized car due to lower technology content compared with other market segments (He & Tu, 2012). SAIC-GM-Wuling, which makes only minivans, and Chang’an are the primary producers of this type of vehicle in China. They produced nearly 90% of the minivans sold in China in 2010.

Based on the special consideration for SAIC-GM-Wuling’s concentration in the minivan segment, we determined the lower cutoff point for footprint at 3.2 m². In determining the top constraint point of the standard curve, we also cut off the 10% largest vehicles by sales—that is, at about 4.45 m².

To determine the slope of the target curve in between the two flat ends, again, we used the 60% slope based on the sales-weighted trend line of the 2010 market data between vehicle footprint and fuel consumption ratings. Therefore, the general mathematical

equation of the target curves for 2015 and 2020 is as follows. Combining with the cutting points, the target curve assigns SAIC-GM-Wuling and a couple of minor manufacturers (representing about 10% of the market) a fixed target of 6.2 L/100 km for 2015, and 4.5 L/100 km for 2020, regardless of their specific fleet sizes; it assigns most import vehicle manufacturers, luxury brands and a few SUV/MPV automakers a flat target of 7.7 L/100 km for 2015, and 5.5 L/100 km for 2020.

The function of the hypothetical 2015 and 2020 standard curves is $Target_i = \text{Min} [\text{Max}(c * X_i + d, a), b]$

Where:

Target_i is the corporate-average fuel consumption target for a given manufacturer *i* in a given target year,

a is the minimum target (L/100 km) and equals 6.2 for 2015 and 4.5 for 2020,

b is the maximum target (L/100 km) and equals 7.7 for 2015 and 5.5 for 2020,

c is the slope of the linear function (L/100 km per m²), and equals 1.09 for 2015 and 0.79 for 2020,

d is the intercept of the curve (L/100 km), and equals 2.8 for 2015 and 2 for 2020, and

X_i is the sales-weighted average footprint of a given manufacturer *i* (m²).

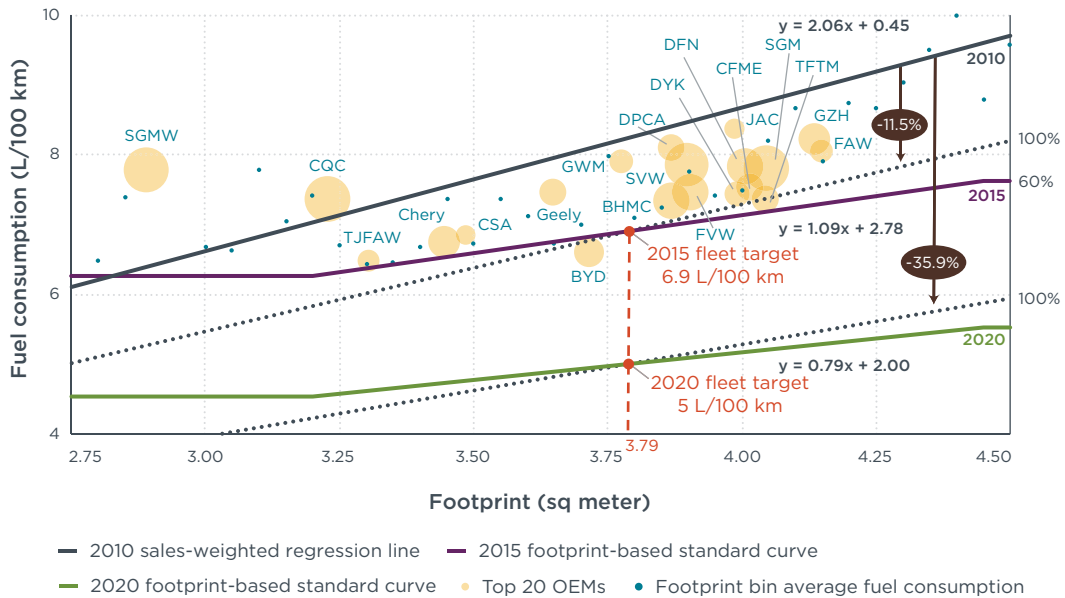


Figure 14. Footprint-based fuel consumption standard for 2015 and 2020

Figure 14 depicts the two target curves, for 2015 and 2020 respectively, and compared with the current performance of each major manufacturers. Figure 15 shows the required percentage reduction of each major manufacturer to meet its specific footprint-based CAFC targets in 2015 and 2020. BYD has already met its footprint target for 2015. Three Chinese independent automakers (Great Wall, JAC, and Chang’an), and two joint ventures (Dongfeng-Citroën-Peugeot and SAIC-GM-Wuling) need greater-than-average improvement to meet their 2015 and 2020 targets. Similar to the previous two forms

of weight-based standards, the minivan automakers rank at the bottom and need the greatest improvement. Again, the impact on manufacturers depends on slope choice of the standard curve.

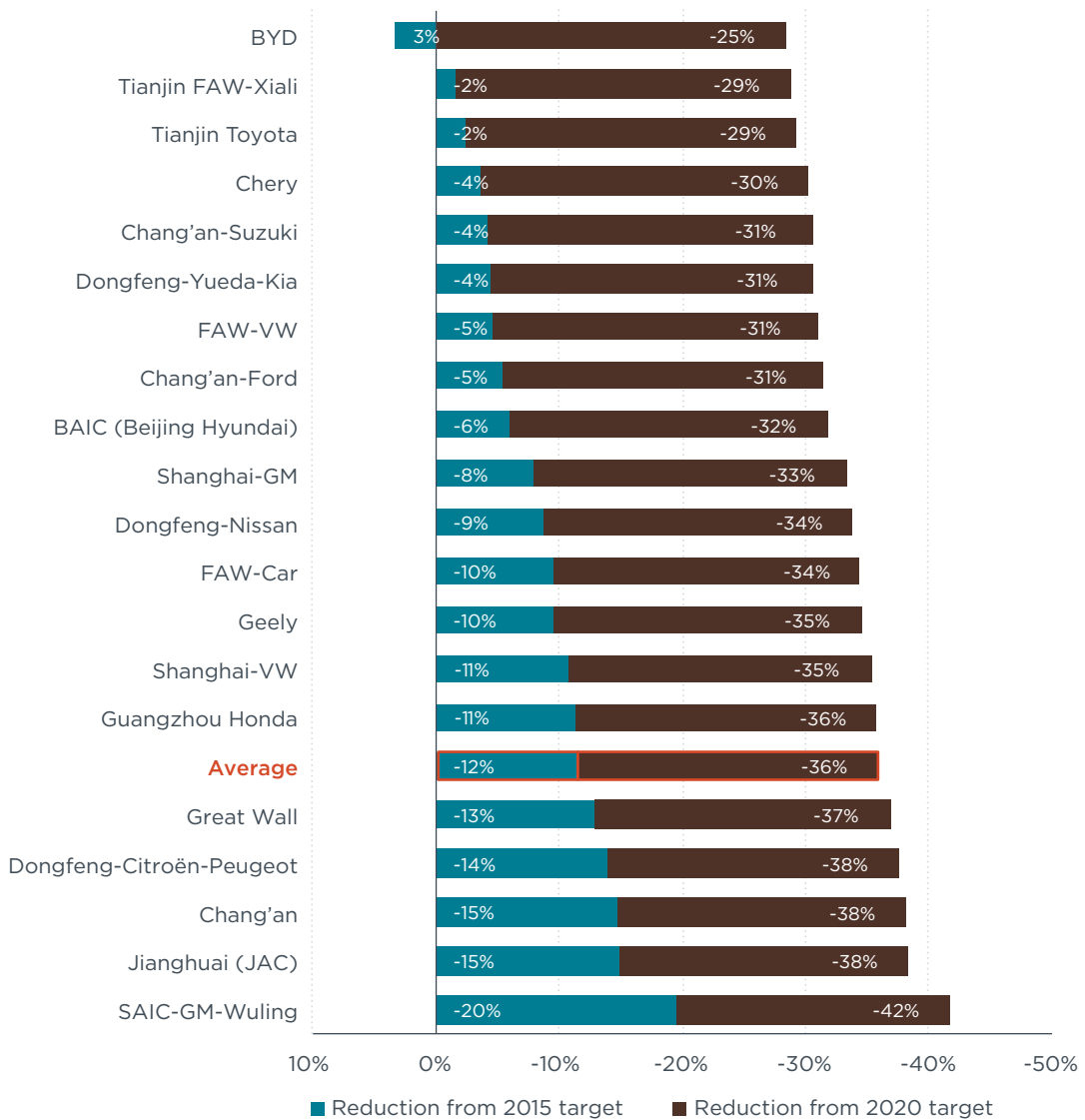


Figure 15. Percentage reduction required to meet hypothetical 2015 and 2020 footprint targets. For BYD, 3 percent reduction represents overcompliance.

3.5 COMPARISON OF MANUFACTURER COMPLIANCE BURDENS UNDER THREE REGULATORY DESIGNS

This section includes two sets of comparisons of compliance burdens. The first set compares corporate average fuel consumption targets and the impact of two alternative standard designs—continuous linear weight-based and piece-wise footprint-based standards—on China’s current weight-bin based standard (Table 6). Because weight bins are defined only under China’s Phase III standards, and it is not clear whether China will continue to use the current bin structure beyond 2015 or not, we did not include the 2020 targets for this comparison.

In general, the differences between the bin-based China Phase III standard and an equally stringent continuous linear weight standard are within reasonably small margins (4%) for the majority of manufacturers. Yet five manufacturers—Tianjin-FAW-Xiali, BYD, Chery, Chang’an-Suzuki, and Geely—will be significantly better off under the continuous weight-based standard than under Phase III targets. Most of them are already the best performers in terms of their absolute CAFC values.

The primary reason is that the slope of our linear weight-based standard curve is flatter than the derived slope of the Phase III standard. Thus, these five manufacturers, which produce lighter vehicles on average, face a lower target under the hypothetical continuous standard. On the other hand, manufacturers that produce heavier vehicles, such as Shanghai-GM, FAW-Car, Guangzhou-Honda, or JAC, face stiffer targets under the hypothetical continuous linear standard.

Another, albeit minor, reason for the differences between Phase III and continuous weight-based standards’ impacts is the elimination of the negative corner effect under the latter structure. For example, the curb weight of BYD’s top-selling F3 model is 1,200 kg, only 5 kg below the threshold of the next weight bin. It is assigned under the Phase III standard with a target of 6.5 L/100 km, instead of a less stringent target of 6.9 L/100 km for the next weight bin. The continuous weight-based standard avoids such a big bump and assigns F3 a target of 6.7 L/100 km.

In short, the continuous weight-based standard with a 60% slope has two important advantages over the Phase III bin-based standard: First, it favors the current best-performing manufacturers with the lightest fleets while further penalizing producers of heavier vehicles. Second, it helps to minimize gaming opportunities and enhances the fairness of a weight-based standard system.

Under the footprint-based standard, manufacturers with lighter fleet and lower absolute CAFC values tend to be better off, while the heavier and fuel-guzzling fleets face tougher targets compared with either Phase III or continuous weight-based standards. Tianjin-FAW and BYD, both producing some of the lightest and smallest cars in the market, gain the most from footprint-based standards. The compliance burden for Tianjin-FAW-Xiali is reduced to only 2% under the footprint-based standard from 16% and 7% under the Phase III standard and the contiguous weight-based standard. The footprint-based standard even turn BYD into 3% over-compliance, compared to 6% and 1% reduction required to meet its 2015 target under Phase III standard and the continuous weight based standard.

Table 6. Comparison of 2015 fuel consumption targets and compliance burdens under various standard design structures

	2010 performance (L/100 km)	Targets (L/100 km)			Required reduction (%) from 2010		
		China phase III	Continuous weight-based	Footprint-based	China phase III	Continuous weight-based	Footprint-based
Tianjin FAW-Xiali	6.5	5.4	6.0	6.4	16%	7%	2%
BYD	6.6	6.2	6.5	6.8	6%	1%	-3%
Chery	6.8	6.3	6.5	6.5	7%	3%	3%
Chang`an-Suzuki	6.9	6.0	6.3	6.6	12%	7%	4%
FAW-VW	7.3	6.9	7.0	7.0	5%	5%	5%
Tianjin Toyota	7.4	6.9	7.0	7.2	6%	5%	2%
Chang'an	7.4	6.2	6.3	6.3	16%	14%	15%
Dongfeng-Yueda-Kia	7.4	6.8	6.9	7.1	9%	7%	4%
Geely	7.5	6.3	6.6	6.7	16%	12%	10%
BAIC (Beijing Hyundai)	7.5	6.9	6.9	7.0	7%	7%	6%
Chang`an-Ford	7.5	6.9	6.9	7.1	9%	8%	5%
SAIC-GM-Wuling	7.8	6.2	6.2	6.3	21%	20%	20%
Average	7.8	6.9	6.9	6.9	11%	11%	11%
Shanghai-GM	7.8	7.2	7.1	7.2	7%	9%	8%
Dongfeng-Nissan	7.8	6.9	6.9	7.1	12%	11%	9%
Shanghai-VW	7.9	6.9	6.9	7.0	12%	12%	11%
Great Wall	7.9	7.1	7.1	6.9	10%	10%	13%
FAW-Car	8.1	7.2	7.1	7.3	10%	11%	10%
Dongfeng-Citroën-Peugeot	8.1	6.9	6.9	7.0	15%	15%	14%
Guangzhou Honda	8.2	7.4	7.2	7.3	10%	12%	11%
Jianghuai (JAC)	8.4	7.5	7.3	7.1	10%	13%	15%

Note: Manufacturers are ordered by their 2010 corporate average fuel consumption performance (low to high)

The majority of the top 20 manufacturers listed in Table 6 face reduced compliance burdens under the footprint-based standard scheme than under the two weight-based standard schemes. Nevertheless, this does not indicate that the footprint-based standard is less stringent in general than the other two standard designs. Rather, this is because a footprint-based standard curve with a 60% slope turns out to be flatter than the continuous weight-based standard curve with a 60% slope or the derived linear curve for the Phase III standard. In this case, the fleet-average fuel consumption will not change across different standard curves, but with appropriate design, policymakers have the flexibility to change target stringency. Though it appears that a size-based standard is easier to meet for major manufacturers, this is not true if considering all manufacturers. Figure 16 and 17 rank all manufacturers in the market by their corporate-average fleet curb weights and footprints, respectively, from left to right, and show the differences in CAFC targets under all three standard designs. It is obvious that the footprint-based standard discourages vehicle and fleet weight increase and upsizing simultaneously more than the other standard designs do.

The second set of comparisons focuses on any potential change in impact on manufacturers under the continuous weight-based and the footprint-based standards from 2015 (near-term) to 2020 (longer-term). As illustrated by Table 7, in the near term, both standards lead to very similar compliance burdens for all manufacturers except for Tianjin-FAW-Xiali and Chang'an Suzuki. In particular, targets under the two standard structures for the largest automakers are nearly identical. The two exceptions face significantly relaxed targets under a footprint-based standard, benefiting from their extremely small and light vehicle fleets and the flat footprint-based standard curve. This trend also holds for 2020 targets. There is no significant difference between Chinese independent OEMs and joint venture companies in terms of how footprint-based targets diverge from weight-based targets.

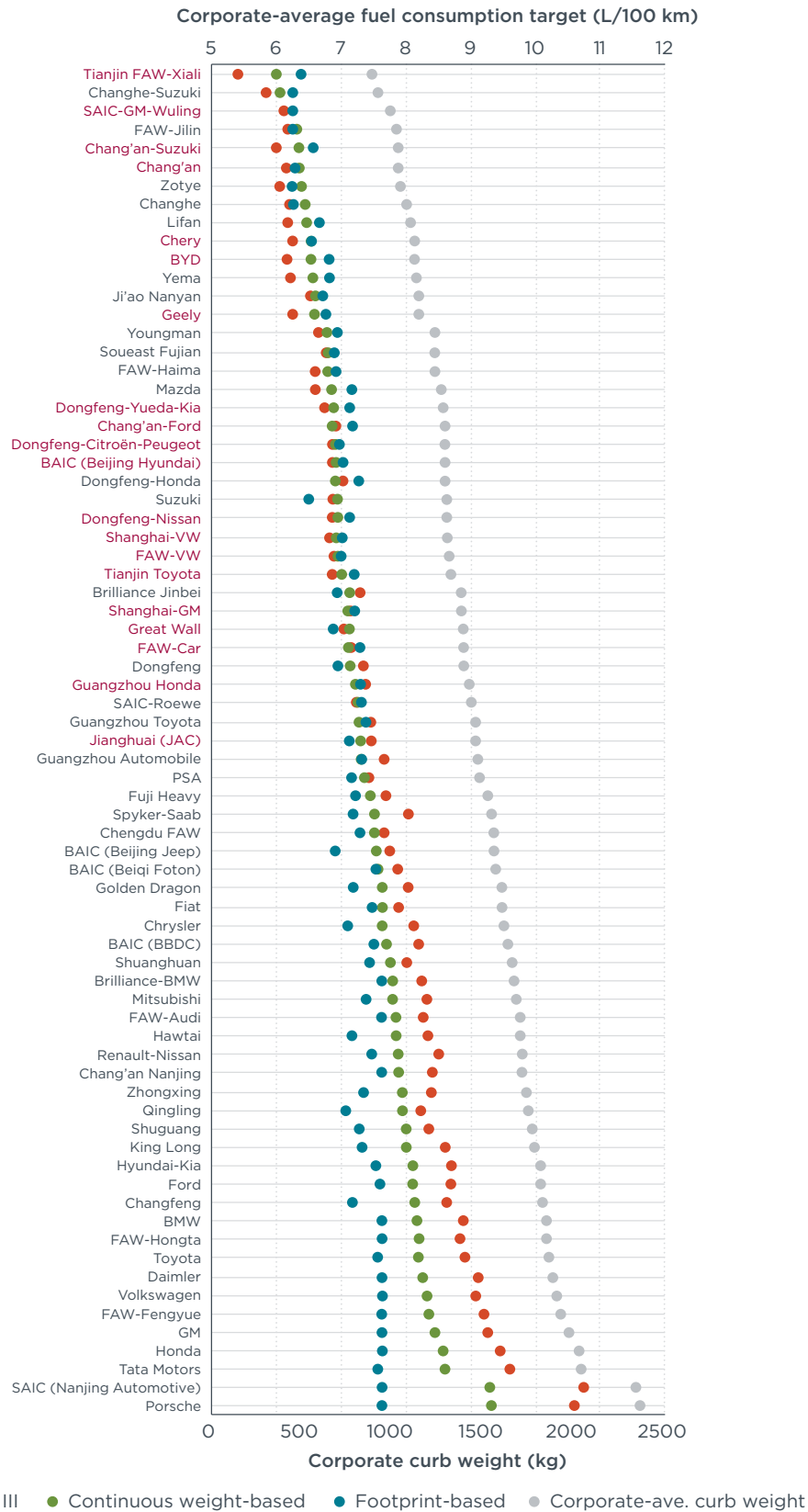


Figure 16. Comparison of CAFC targets for all manufacturers with manufacturers ranked by corporate-average fleet weight

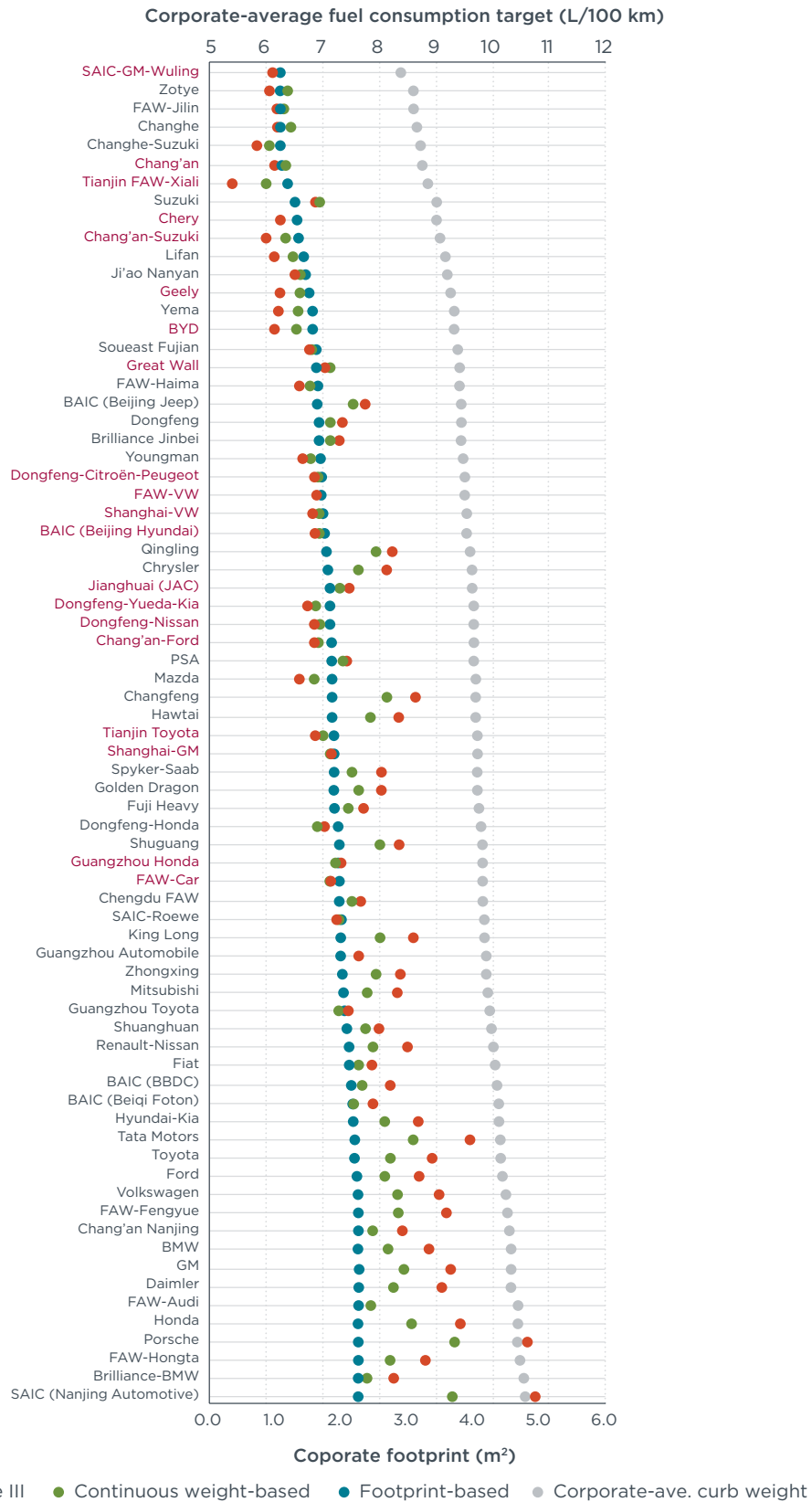


Figure 17. Comparison of CAFC targets for all manufacturers with manufacturers ranked by corporate-average fleet footprint

Note: The top 20 manufacturers are highlighted in red font in both Figure 16 and 17.

Table 7. Comparison of 2015 and 2020 compliance burdens between continuous weight- and footprint-based standard structures by manufacturer type

Manufacturer size and type	Manufacturers	Phase III	2015 weight standard	2015 footprint standard	2015 size-weight standard difference	2020 weight standard	2020 footprint standard	2020 size-weight standard difference
1.1 Mil	● Chang'an	6.2	6.3	6.3	█	4.6	4.6	█
	● Shanghai-GM	7.2	7.1	7.2	█	5.2	5.2	█
	● SAIC-GM-Wuling	6.2	6.2	6.3	█	4.5	4.5	█
	● Shanghai-VW	6.9	6.9	7.0	█	5.0	5.1	█
	● BAIC (Beijing Hyundai)	6.9	6.9	7.0	█	5.0	5.1	█
	● Dongfeng-Nissan	6.9	6.9	7.1	█	5.0	5.2	█
	● FAW-VW	6.9	7.0	7.0	█	5.0	5.1	█
	● Chery	6.3	6.5	6.5	█	4.7	4.7	█
	● Guangzhou Honda	7.4	7.2	7.3	█	5.2	5.3	█
	● BYD	6.2	6.5	6.8	█	4.7	4.9	█
	● Chang'an-Ford	6.9	6.9	7.1	█	5.0	5.2	█
	● Tianjin Toyota	6.9	7.0	7.2	█	5.1	5.2	█
	● Geely	6.3	6.6	6.7	█	4.8	4.9	█
	● Dongfeng-Citroën-Peugeot	6.9	6.9	7.0	█	5.0	5.1	█
● Dongfeng-Yueda-Kia	6.8	6.9	7.1	█	5.0	5.2	█	
0.2 Mil	● Great Wall	7.1	7.1	6.9	█	5.2	5.0	█
	● FAW-Car	7.2	7.1	7.3	█	5.2	5.3	█
	● Tianjin FAW-Xiali	5.4	6.0	6.4	█	4.4	4.6	█
	● Jianghuai (JAC)	7.5	7.3	7.1	█	5.3	5.2	█
	● Chang'an-Suzuki	6.0	6.3	6.6	█	4.6	4.8	█

Bars labeled in green indicate significant change (equal or more than 4% difference in absolute value)

Notes: [1] Brown dots and lines denote Chinese independent manufacturers. [2] Blue dots and lines denote joint venture manufacturers. [3] Size-weight standard difference is the percentage difference between size-based and weight-based CAFC standard for each manufacturer.

4 CONCLUSION

Our analysis reached the following conclusions:

- » A footprint-based standard is more technology-neutral than a weight-based standard, and therefore reduces compliance costs for manufacturers to meet more stringent long-term targets.
- » Our hypothetical footprint-based standard better rewards manufacturers producing lighter vehicles and penalizing heavier vehicles, compared with a weight-based standard of the same slope choice, without alternating the overall fleet fuel consumption targets for 2015 or 2020.
- » Our hypothetical footprint-based standard does not discriminate against or artificially favor either joint venture automakers or Chinese independent OEMs.
- » A continuous weight-based system offers a minor benefit of minimizing gaming in vehicle weight and enhancing the fairness of manufacturers.

Based on the findings of this paper, we arrive at the following recommendations for China:

- » If China would like to stick to a vehicle utility parameter to set its fuel consumption standards, vehicle footprint is a better choice than curb weight to enable all efficiency improvement technologies, including vehicle mass reduction. Lightweighting is going to be a vital option globally, and the Chinese vehicle fuel consumption standard system should anticipate this trend by allowing it as a vital option.
- » If data are not complete enough to set footprint-based standards immediately, changing from the current weight bin-based standard to a continuous linear weight based standard with a flatter slope than the current one will offer some important benefits.
- » While standard structure is critical, other design elements also determine the stringency and overall effectiveness of a standard. These elements include:
 - » The slope of the standard curves should be low enough to avoid gaming and fleet upsizing/weight increase.
 - » The pivot point/center of gravity of a liner standard curve should reflect the regulatory target of the entire fleet.
 - » If necessary, the fuel consumption target can be capped (set constant beyond a particular footprint level) for the largest or heaviest vehicles to further avoid upsizing/weight increase.

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APPENDIX I:

Manufacturers' acronyms

OEMs	Abbreviations
Chang'an	CQC
Shanghai-GM	SGM
SAIC-GM-Wuling	SGMW
Shanghai-VW	SVW
BAIC (Beijing Hyundai)	BHMC
Dongfeng-Nissan	DFN
FAW-VW	FVW
Chery	Chery
Guangzhou Honda	GZH
BYD	BYD
Chang'an-Ford	CFME
Tianjin Toyota	TFTM
Geely	Geely
Dongfeng-Citroën-Peugeot	DPCA
Dongfeng-Yueda-Kia	DYK
Great Wall	GWM
FAW-Car	FAW
Tianjin FAW-Xiali	TJFAW
Jianghuai (JAC)	JAC
Chang'an-Suzuki	CSA