Chapter 30
Analysis on China's Fuel Consumption Standards and Its Influences on Curb Weight

Xiao Li, Fuquan Zhao, Han Hao and Zongwei Liu

Abstract With the explosive growth of China's vehicle ownership, energy consumption and emissions from passenger vehicles become a major concern. The fuel consumption standards for passenger vehicles play an essential role in addressing such issues. In this study, four most important aspects of China's fuel consumption standards, i.e., evaluation standard, constraint form, basic curb weight and the slope, are investigated. By establishing the database comprising the major characteristics of 2010–2015 new vehicles, the rationale of each aspect and the influences on China's vehicle market and manufacture are analyzed. The results indicate that the evaluation standard and constraint form have strong impacts on the motivation of manipulation and the stress of achieving the standard targets. On the other hand, the basic curb weight and the slope have strong impacts on the change of curb weight and technology friendliness of lightweighting.

Keywords Fuel consumption standards · The standard targets · Curb weight

30.1 Introduction

Facing the increasingly severe challenges of energy crisis and environmental degradation, China began to implement fuel consumption standards as from 2005, including four phases of year 2005–2008, 2009–2012, 2012–2015 and 2016–2020 [1], as is shown in Fig. 30.1. Among them, phase I and phase II regulate fuel consumption limits according to the curb weight, but there is no actual statistics, constraint or punishment. From phase III, China introduced the concept of CAFC

X. Li · F. Zhao · H. Hao · Z. Liu (✉)
State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China
e-mail: zw.liu@gast-group.com

X. Li · F. Zhao · H. Hao · Z. Liu
Tsinghua Automotive Strategy Research Institute, Tsinghua University, Beijing 100084, China

Society of Automotive Engineers of China (SAE-China), *Proceedings of SAE-China Congress 2016: Selected Papers*, Lecture Notes in Electrical Engineering 418,
DOI 10.1007/978-981-10-3527-2_30

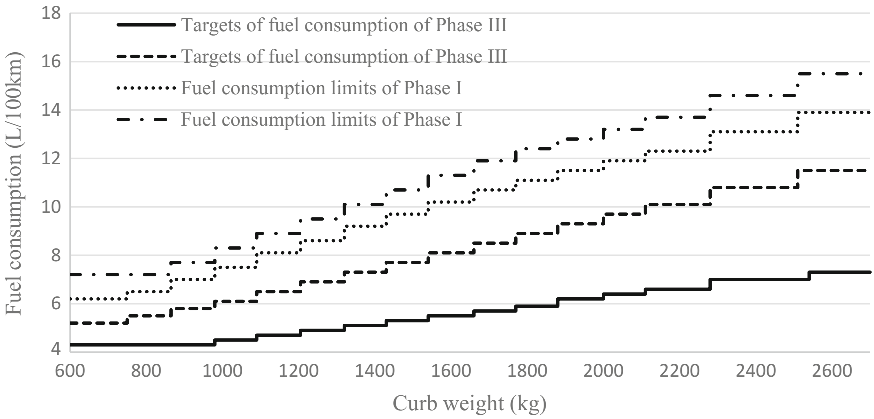

Fig. 30.1 Four phases of China's fuel consumption standards

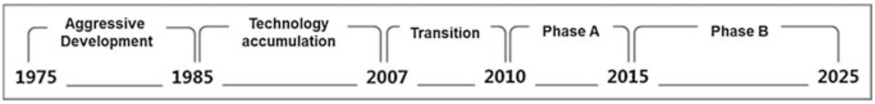

Fig. 30.2 Development processes of the world's CAFC standards

(Corporate Average Fuel Consumption), and relevant departments set up the targets for the average fuel consumption of passenger car corporations [2]. Ministry of Industry and Information Technology (MIIT) of China began to make statistics and notifications of the CAFC targets of various Chinese corporations. The corresponding monitoring scheme Management Measures of the CAFC would be issued. China's CAFC standard is gradually playing an essential role in energy saving and emission reduction.

The setup of CAFC standards in China is not groundless, the US, Europe and Japan all issued their fuel consumption standards ahead of China. Figure 30.2 describes the development of the CAFC standards worldwide. The US formulated the stringent CAFE standard during the first oil crisis period at 1975. Till 1985, the average fuel economy of passenger car in the US increased from 13.5 to 27.5 mpg [3], and the doubled fuel economy during a decade had profound impacts to the world's automobile manufacturing industry. Entering into the new century, global warming becomes increasingly serious, with world's focuses on carbon emission control problem. Various countries begin to issue a next round of standards, with general formation of two phases of A and B, with 2015 and 2025 as time nodes.

Since 2012, China's fuel consumption standards has entered into Phase III, MIIT of China required all corporations to report their targets and actual performances, and publicize them. Table 30.1 is the condition of reaching the target of CAFC standard by corporations. As can be seen, the target of Phase III is implemented smoothly. Though MIIT of China does not publicize the statistics of CAFC in 2015,

Table 30.1 Implementation of CAFC standard in China in 2014 [4]

Type of enterprise	Target of CAFC (L/100 km)	Actual performance (L/100 km)	Proportion of the actual performance to the target (%)
Indigenous enterprise	7.40	7.10	96.0
Joint venture	7.29	7.15	98.0
Import enterprise	9.20	8.76	95.2

the average fuel consumption in China reduces by 4% every year. It is predicted that the target of Phase III can be achieved successfully.

In 2015, MIIT of China noticed 1448 new models passenger cars, and the situation of reaching the target by different models refers to Fig. 30.3. Among them, there are 870 models that reach the target of Phase III, accounting for 60% of the total noticed models. There are 30 models that reach the target of Phase IV, accounting for 2% of the total noticed models. Combined with specific models, models that have heavier curb weight are in poor condition to reach the target, however, A-class and B-class models that occupy the market mainstream are in good conditions to reach the target. The models that reach the targets of Phase IV are mainly hybrid electric vehicles.

This paper conducts detailed description and argumentation for the contributing factors of passenger car fuel consumption standards at Phase IV. Combined with the data of actual models, this paper analyzes the impacts of fuel consumption standards.

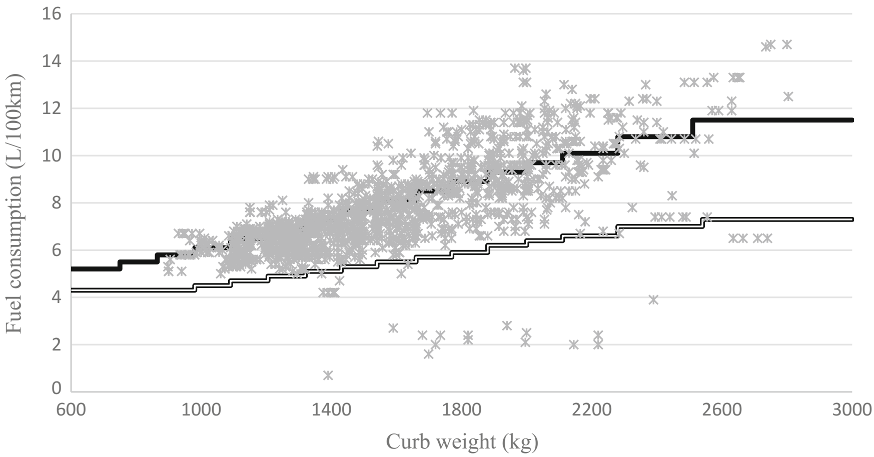

Fig. 30.3 The condition of reaching the targets of Chinese new models in 2015

30.2 The Evaluation Standard and Constraint Form of China's CAFC Standard

30.2.1 Causes of the Evaluation Standard and Constraint Form

China's fuel consumption standards regard passenger car curb weight as the evaluation standard, and give out limits or targets for fuel consumptions of passenger cars at different weight ranges with the step-shaped constraint form, which is similar to that of the Japanese standards. Table 30.2 shows the evaluation standards and constraint forms of fuel consumption standards in different countries.

Except North America, other regions in the world mainly adopt curb weight as the evaluation standard. Relevant studies have compared different evaluation standards such as curb weight, footprint and power, and results show that compared with footprint, fuel consumption standards that take curb weight as the evaluation standard has poor friendliness to the application of automotive energy saving technologies [5, 7]. However, when designing fuel consumption limits, we shall not only consider the advantages and disadvantages of the evaluation standards themselves, but also consider the test method for fuel consumption, therefore, most countries in the world adopt curb weight as the evaluation standard. The fuel consumption test methods in regions like China, Japan and the European Union have profound historical origins with the standard formulated by UNECE (United Nations Economic Commission for Europe). Among them, China adopts *Test Methods for Fuel Consumption of Light-Duty Vehicles* (GB/T 19233-2008), an d basically follows the standard by UNECE. China categorizes the vehicle reference mass according to weight ranges, and set the corresponding equivalent inertia and dynamometer resistance coefficient according to weight ranges. The reference masses of passenger cars are categorized into 22 weight ranges, and every reference mass has its corresponding equivalent inertia, absorbed power and load and

Table 30.2 Evaluation standards and constraint forms of fuel economy standards in major countries and regions in the world [5, 6]

Country	Constraint unit	Constraint form	Evaluation standard	Test cycle
China	Fuel consumption per hundred kilometers (L/100 km)	Step-shaped	Curb weight (kg)	NEDC
Japan	Fuel economy (km/L)	Step-shaped	Curb weight (kg)	JC08
EU	Carbon emission CO_2 (g/km)	Linear	Curb weight (kg)	NEDC
North America (including Canada and Mexico)	Fuel economy (mpg)	Linear	Footprint (ft^2)	CAFE

Table 30.3 Correspondings set methods for dynamometers at different curb weight ranges [8, 9]

			Set of dynamometer (80 km/h)		Coefficient	
Curb weight (kg)	Basic weight (kg)	Equivalent inertia (kg)	Power (kW)	Load (N)	Curb weight (kg)	Basic weight (kg)
750–865	850–965	910	5.6	252	5.7	0.0385
865–980	965–1080	1020	6	270	6.1	0.0412
980–1090	1080–1190	1130	6.3	284	6.4	0.0433
1090–1205	1190–1305	1250	6.7	302	6.8	0.046
1205–1320	1305–1420	1360	7	315	7.1	0.0481
1320–1430	1420–1530	1470	7.3	329	7.4	0.0502
1430–1540	1530–1640	1590	7.5	338	7.6	0.0515
1540–1660	1640–1760	1700	7.8	351	7.9	0.0536
1660–1770	1760–1870	1810	8.1	365	8.2	0.0557
1770–1880	1870–1980	1930	8.4	378	8.5	0.0577
1880–2000	1980–2100	2040	8.6	387	8.7	0.0591
2000–2110	2100–2210	2150	8.8	396	8.9	0.0605
2110–2280	2210–2380	2270	9	405	9.1	0.0619
2280–2510	2380–2610	2270	9.4	423	9.5	0.0646
>2510	>2610	2270	9.8	441	9.9	0.0674

resistance coefficient, which explains that vehicles at the same reference mass will obtain the same resistance from the dynamometers. Chinese standards describe vehicle reference mass as "adding 100 kg to vehicle curb weight". Table 30.3 gives out the setting method for dynamometers combined with the set of dynamometers and the weight ranges in China's CAFC of appendix 1 CB1 of *Limits and Measurement Methods for Exhaust Pollutants from Light-Duty Vehicles* (GB 18352.3-2005, test method for fuel consumption refers to this standard). Table 30.3 shows for vehicles at the same weight ranges, the set of dynamometer is fair, and it is reasonable that China's fuel consumption standards regard curb weight range as the evaluation standard, and step-shape as the constraint form to design fuel consumption limits and targets.

30.2.2 The Influence of Evaluation Standard and Constraint Form

According to the resistance coefficient set for the dynamometers, it is reasonable to take curb weight as the evaluation standard, and step-shape as the constraint form for vehicle with different weights at the same weigh ranges. But China's fuel consumption test method does not strictly implement look-up table, and the *Test*

Methods for Fuel Consumption of Light-Duty Vehicles (GB/T 19233-2008) points out that, "the driving resistance curve is provided by automobile manufacturers, and manufacturers shall provide test reports, calculation reports and other relevant materials, which shall be confirmed by inspection agencies", and "if automobile manufacturers request, driving resistance can be selected by the look-up table" [9]. Different models have different driving resistance curves, and the changes of curb weights have direct impacts on this. If test resistance curves are provided by automobile manufacturers, and under the same weight ranges, with other variables remaining the same, models of light weight have certain advantages compared with models of heavy weight, making the step-shaped standard lose its fairness.

If the resistance curves are provided by enterprises, adding a little weight to the vehicles with comparatively heavier weight in small weight ranges can make vehicles enter into the next weight range under the condition of no big impact to resistance curves, thus the target is loosened. While models at this weight range can reduce curb weight to gain better resistance curves, with unchanged target. Therefore, the 10% before curb weight enters into the weight range reduces the difficulties to achieve the target to some extent, and define the models with curb weight that is 10% ahead of weight range as the "manipulation" models [10]. This study further analyzes the "manipulation" phenomenon based on previous studies.

Figure 30.4 shows from 2013 to 2015, the proportion of "manipulation" models remains at 18%, which is obviously higher than other model types. This shows that some enterprises adopt the "manipulation" method to cope with the fuel consumption standards of passenger cars in China. However, this phenomenon is not universal, and has no trend of further improvement. Figure 30.5 describes the manipulation of new models from 2013 to 2015 in China. View from different enterprise types, indigenous brands have obvious "manipulation" phenomenon, with the use of "manipulation" method by over 20% of models. While joint ventures do not have obvious "manipulation" behavior. There are mainly two reasons for this. First, the major market of indigenous brands is China, and indigenous brands consider to meet the CAFC standard at the initial design stage. Besides, indigenous brands are poor in energy saving technology, compelling enterprises to adopt "manipulation" to reach the targets. Second, the products of joint ventures are

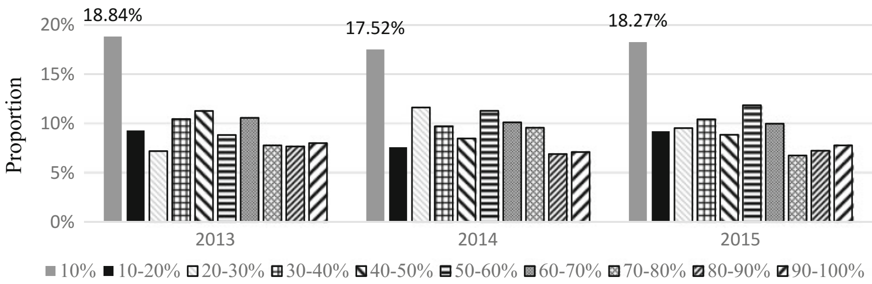

Fig. 30.4 Distribution proportion of new models in the corresponding weight ranges from 2013 to 2015 in China

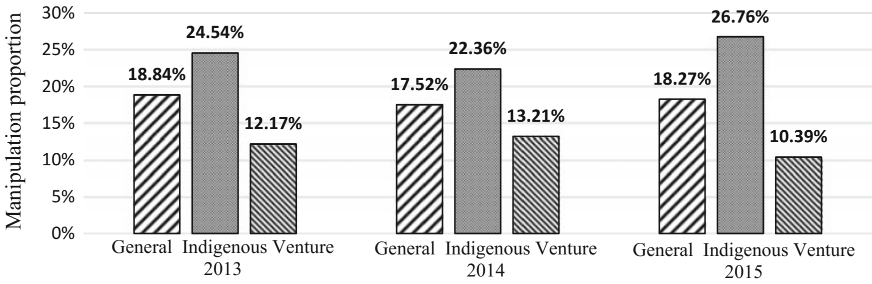

Fig. 30.5 Manipulation of new models from 2013 to 2015 in China (according to enterprises' types)

most foreign models that are introduced to China, and the models are not specially designed to meet the China's CAFC standard. Joint ventures have high levels in energy saving technologies, and do not need "manipulation".

CAFC standard adopts curb weight as the evaluation standard and step-shape as the constraint form. When models at different curb weight ranges begin lightweighting to reach the next weight ranges, they will face different pressures in reaching the target. Define the pressure in reaching the target as Eq. 30.1:

$$\mathrm{P} = \frac{\frac{\Delta F}{F} * 100\%}{\frac{\Delta M}{M} * 100\%} \tag{30.1}$$

P is the pressure in reaching the target, F is the fuel consumption target of this weight range, ΔF is the difference in fuel consumption targets of two weight ranges, M is the weight of the vehicle, ΔM is weight reduction from this weight range to the next weight range. The physical significance of pressure in reaching the target is the fuel consumption reduction proportion to divide the weight reduction proportion. The bigger the pressure in reaching the target of the corresponding weight range means more fuel consumption reduction is required for the model to enter into the next weight range through lightweighting.

Analyzing the CAFC standard of Phase III and Phase IV, Fig. 30.6 describes the pressures in reaching the targets of different weight ranges and the "manipulation" proportion of the corresponding weight range in 2015. With the increase of curb weight, there is a trend of increase for the pressure in reaching the target comprehensively. The pressure in reaching the target shows a saltus at 2000–2110 kg for Phase III, and at 1880–2000 kg for Phase IV. Combined with the "manipulation" phenomenon, year 2015 is at Phase III of the CAFC standard, and the weight range of 2000–2110 kg that saltus occurs in the pressure of reaching the target has high "manipulation" proportion, which means the "manipulation" behavior is closely related to the pressure in reaching the target. The overly high pressure in reaching the target enhances the motivation for enterprises' "manipulation". Thus we can infer that by 2020, the weight range with the highest "manipulation"

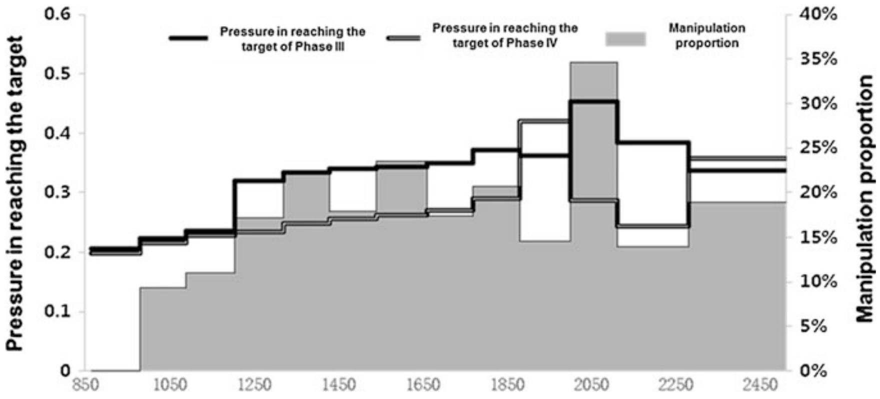

Fig. 30.6 Relationship between the pressure in reaching the targets of Phase III and Phase IV and the "manipulation" phenomenon

proportion will move left to 1880–2000 kg of Phase IV standard that fuel consumption reduction pressure saltus. Besides, Fig. 30.6 shows weight ranges of 1320–1430 kg and 1540–1660 kg have strong "manipulation" phenomenon and these two ranges cover the best-selling A-class and B-class vehicles in the Chinese market. Though the pressure in reaching the target is not strong, the high sales volume has high weight in the calculation of CAFC target. "Manipulation" behavior is beneficial for reducing the difficulties for enterprises in reaching the target.

30.3 Changes of the Slope of China's CAFC Standards and Its Influence

30.3.1 Changes of the Slopes of Fuel Consumption at Phase IV in China

The fuel consumption standards are categorized according to the constraint forms in China. Phase I and Phase II are limits and Phase III and Phase IV are targets. However, view from time nodes, the fuel consumption standards meet the categorization methods of Fig. 30.2. Among them, Phase I and Phase II are transition stages, and Phase III is Phase A. Achieve the target of 6.9 L/100 km by 2015. Phase IV and Phase V in future will be Phase B, and achieve the target of 5 L/100 km at Phase IV by 2015; Phase V has not been released yet, and it is projected to take year 2025 as the time node, which is similar to most countries in the world. Details refer to Table 30.4.

Analyze China's fuel consumption standards according to this trend. Figure 30.7 describes the reduction change of fuel consumption standards during the first three

Table 30.4 Fuel consumption targets according to phases in major countries of the world [11]

Country	Phase A (2015)	Phase B (2020)
China (L/100 km)	6.9	5.0
Japan (km/L)	16.8	20.3
EU (g/km)	130	95
US	36.2 mpg (2017)	56.2 mpg (2025)

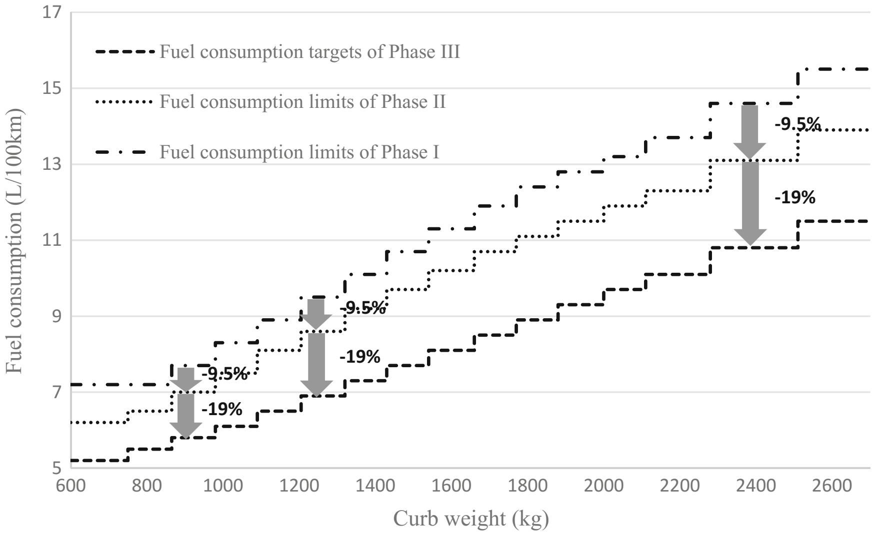

Fig. 30.7 Changes of China's fuel consumption standards in the first three phases

phases. Among them, the reduction of fuel consumption reaches to 9.5% at Phase II, and that of Phase III reaches to 19%. Every weight range calculates the limits and targets according to the reduction of the former phase directly. These three phases all regard the weight range of 1250–1320 kg as "base", meaning the average weight range of the passenger cars under this phase. The corresponding limits or targets are the overall limits and targets of passenger cars under this phase.

The slope of CAFC standard at Phase IV in China has changes, and is no longer the single equal proportion reduction. Figure 30.8 describes the formulation steps of the standard of Phase IV. To make better understanding, Fig. 30.8 takes the line of linear regression and slope change to describe the formulation steps:

① Determine the reduction, and the corresponding weight reduction proportion, namely $(6.9 - 5.1) / 6.9 = 26\%$

② Choose the basic weight range, and adjust the basic weight range of CAFC standard at Phase IV to 1320–1430 kg, and move the standard right

③ Take basic weigh range as the pivot point, and multiply the slope of ② by 70%.

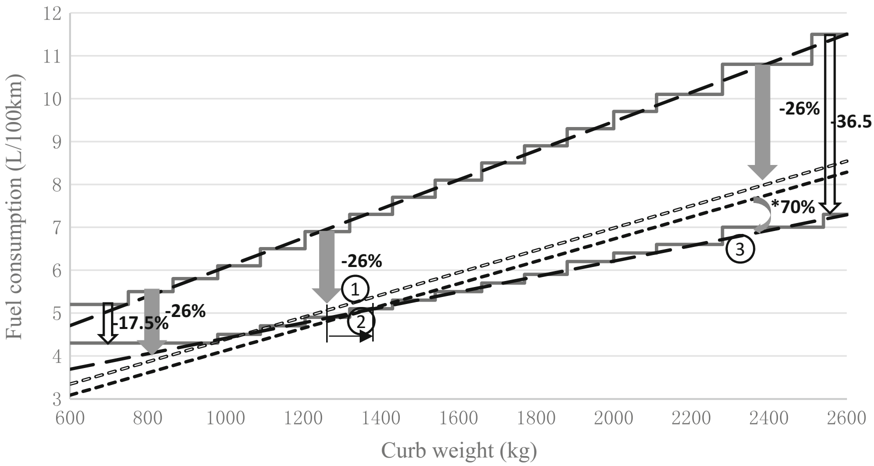

Fig. 30.8 Changes of China's fuel consumption standards at Phase III and Phase IV

The rotating line has different standard formulation compared with the first three phases. The CAFC standard of Phase IV is more mature, which is shown in two aspects. First, increase the basic weight range to 1320–1430 kg, and fully consider the reality of the increase of curb weight of passenger cars in China; second, rotate the constraint line of target, and models with different weights face unequal reductions from 17.5 to 36.5%, which is more suitable for the application laws of energy saving technologies.

30.3.2 The Influence of the Change of Slope of Fuel Consumption Standard at Phase IV in China to Curb Weight

The average curb weight of passenger car is the weighted average with sales as the weight. Table 30.5 is the change of average curb weight released by MIIT of China. The curb weight of passenger car in China at Phase III increases continuously. Figure 30.9 makes statistics of the proportion of noticed models at all weight ranges in the noticed models of that year, and the new noticed models with the largest proportion changes from 1090–1205 kg to 1205–1320 kg gradually, confirming the phenomenon of curb weight increase.

Table 30.5 Change of average curb weight of passenger car in China [11, 12]

Year	2nd half of 2012	2013	2014
Average curb weight	1339	1355	1371

As is known to all, lightweighting is an effective approach to improve vehicle fuel economy [13–15]. In recent years, Chinese and foreign enterprises attach importance to lightweighting, making lightweighting become a commonly automotive technology trend recognized by the industry. However, view from Table 30.5 and Fig. 30.9, under the comparatively stringent standard restrictions of Phase III, the weight of passenger cars in China increases rather than reduces, and the reason for this is complex. On the one hand, this correlates with the high growth rate of market shares of SUV and MPV, and on the other, this correlates with the increasingly rich configurations of passenger cars. However, under stringent CAFC standard, there is still room for growth, which correlates with the constraint of standards themselves. Section 2.1 of this study introduces the slope changes of CAFC standards in China, and it can be seen that the constraints for the first three phases all reduce in proportion, and when vehicles with different weights face the targets of fuel consumption reduction with same proportion, there is no special constraints for vehicles with comparatively heavy weight. The data shows, when vehicle weight is reduced by 100 kg, the corresponding fuel consumption will be reduced by 0.35 L–0.64 L/100 km, and the numerical value is the result of the linear regression of passenger car curb weight and fuel consumption [14]. Constrained by CAFC standard, the linear relation between passenger cars and fuel consumptions is similar to the standard slope in China. Figure 30.10 conducts the linear regression to new models in 2015, and when weight is reduced by 100 kg, the fuel consumption is reduced by 0.37 L/100 km. The regression line basically coincides with the standard of Phase III.

Figure 30.11 shows that if we set up the standard of the next stage with reduction in proportion, the absolute value of fuel consumption required to be

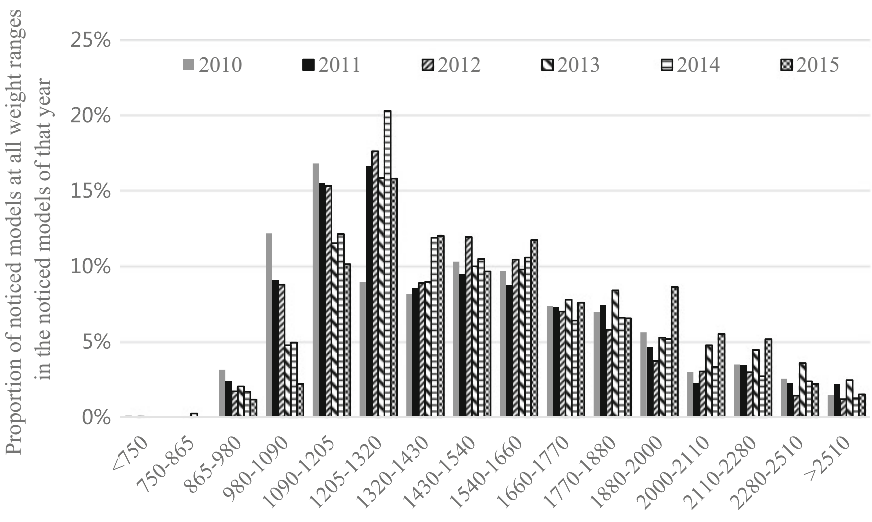

Fig. 30.9 Change of the proportion of noticed models at all weight ranges in the noticed models of that year

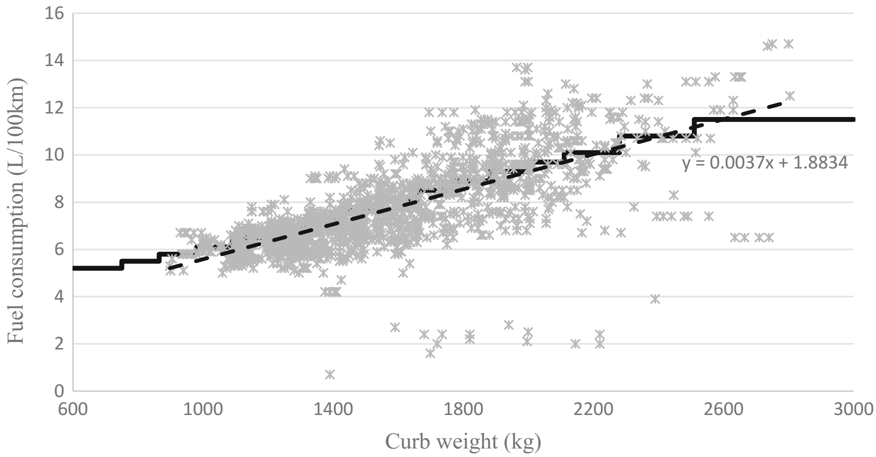

Fig. 30.10 Relationship between China's CAFC standard of Phase III and new models in 2015

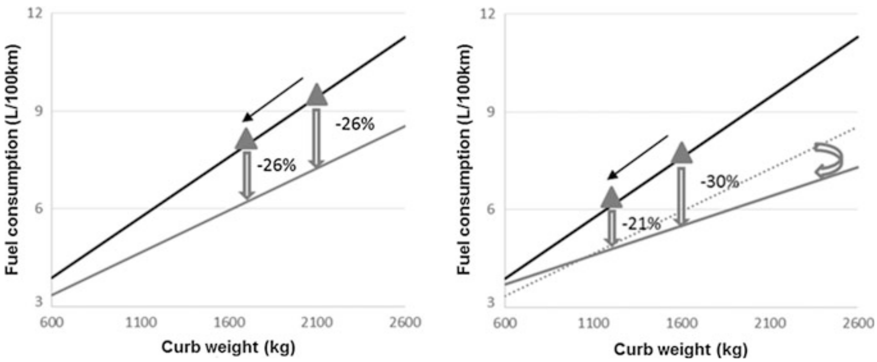

Fig. 30.11 Influence of the change of slope to the motivation of lightweighting

reduced after lightweighting has certain reduction, but the reduction remains unchanged, which counteracts the fuel saving effectiveness to certain degree. If the standard of the next stage conducts the rotation of a certain angle, the fuel consumption reduction required after lightweighting will be reduced. Influenced by the reduction in proportion of fuel consumption standards of the first three phases in China, the fuel saving effectiveness brought by lightweighting is weakened. Chinese passenger car enterprises are not active in the application of lightweighting technologies.

At Phase IV, on the basis of reduction in proportion of China's CAFC standard, it multiplies the slope by a certain proportion, featuring more friendliness to automotive lightweighting technology. Models with comparatively heavier weight will face more stringent targets, and models with comparatively lighter weight will loosen the targets, forming the pattern of "constraining the large vehicles while encouraging the small vehicles". According to the experience of Europe, multiplying the slope by 40–60% has good impacts to the pattern of "constraining large vehicles while encouraging small vehicles". China selects the proportion of 70%, which is more flexible than Europe. However, considering the differences in auto market structures between China and Europe and it is the first time for China to rotate the slope, this proportion is comparatively reasonable, with further consideration of rotating the slope in the CAFC standard at the successive Phase V to implement the favorable policy guidance of "constraining large vehicles while encouraging small vehicles".

30.4 Conclusion

(1) The fuel consumption standard with curb weight as the evaluation standard and step-shape as the constraint form brings certain "manipulation" motivation for enterprises. The proportion of "manipulation" models stabilizes at around 18%, and indigenous enterprises have stronger motivation for "manipulation" than joint ventures.
(2) The pressure for reaching the target has close relationship with "manipulation". The high pressure for reaching the target strengthens the motivation for enterprises' "manipulation". It is predicted that by 2020, the weight range with the highest "manipulation" proportion in 2020 will be 1880–2000 kg.
(3) During the implementation period of the first three phases in China, the average curb weight of passenger car increases instead of reducing, which correlates with the reduction in proportion of fuel consumption standards. The improper setting of the slope of CAFC standard counteracts the fuel saving effectiveness of lightweighting technologies.
(4) The standard of Phase IV in China increases the basic weight, and meanwhile multiplies the slope by 70%, forming the effectiveness of "constraining large vehicles while encouraging small vehicles", and it is predicted that the average curb weight of passenger cars from 2015 to 2020 will stabilize at the basic weight range, featuring better application of lightweighting technologies.

References

1. National Standards of the People's Republic of China (2014) Fuel consumption limits for passenger cars, GB19578-2014
2. Zhao F, Hao H, Liu Z (2015) Technology strategy to meet China's 502 L/10002 km fuel consumption target for passenger vehicles in 2020. Clean Technol Environ Policy
3. Cheah LW (2010) Cars on a diet: the material and energy impacts of passenger vehicle weight reduction in the US. Massachusetts Institute of Technology

4. Feng AN (2015) China passenger vehicle fuel consumption development annual report 2015. Innovation Center for Energy and Transportation, Beijing
5. He H, Yang Z (2013) Incentivizing vehicle mass reduction technologies via size-based passenger car fuel consumption standards in china. ICCT
6. Hao H, Wang S, Liu Z, Zhao F (2016) The impact of stepped fuel economy targets on automaker's light-weighting strategy: the China case. Energy 94:755–765
7. Mock P (2011) Evaluation of parameter-based vehicle emissions targets in the EU. ICCT
8. National Standards of the People's Republic of China (2008) Measurement methods of fuel consumption for light-duty vehicles, GB/T19233-2008
9. National Standards of the People's Republic of China (2005) Limits and measurement methods emission from light-duty vehicles, GB 18352.3-2005
10. Hao H, Wang S, Liu Z, F Zhao. Impacts of China's CAFC standards on light-weighting strategy of automotive manufacturers. In: Proceedings of 2015 SAE-China congress 2015, vol 4
11. Department of Equipment Industry, Ministry of Industry and Information Technology (MIIT) of China. Interpretation of fuel consumption of passenger cars at phase IV [EB/OL]. http://www.miit.gov.cn/n11293472/n11293832/n11294042/n11481465/16423221.html
12. National Standards of the People's Republic of China (2014) Fuel consumption evaluation methods and targets for passenger cars, GB27999-2014
13. Zhao F-Q, Liu Z (2015) China's 5 L/100 km target in 2020 challenges the growth pattern of self-owned enterprises. Auto Mobile Sci Technol 2:1–4
14. SAE-China (2013) Trace research on world automotive technology development lightweight. Beijing Institute of Technology Press, Beijing pp 15–16
15. SAE-China (2015) China automotive lightweight development—strategy and path. Beijing Institute of Technology Press, Beijing, pp 32–33