A PSFI-based analysis on the energy efficiency potential of China’s domestic passenger vehicles

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Abstract. In this article, China’s domestic passenger vehicles (excluding new energy vehicles) are categorized into two groups: local brand vehicles and vehicles manufactured by joint ventures. Performance-Size-Fuel economy Index (PSFI) will be applied to analyse the speed of technical progress and the future trends of these vehicles. In addition, a forecast on energy efficiency potential of domestic passenger vehicles from 2016 to 2020 will be made based on different Emphasis on Reducing Fuel Consumption (ERFC) scenarios. According to the study, if the process of technical progress continues at its current speed, domestic ICE passenger vehicles will hardly meet Phase IV requirements by 2020 even though companies contribute as much technical progress to fuel consumption reduction as possible.

1. Introduction
On January 1 2013, Fuel Consumption Limits for Passenger Cars (GB19578-2014) and Fuel Consumption Evaluation Methods and Targets for Passenger Cars (GB27999-2014) were officially released, enabling China to enter Phase IV of fuel consumption administration. It is required that the average fuel consumption of passenger vehicles should be reduced to around 5L/100km by 2020 [1][2]. Although new energy vehicles (NEV) enjoy favorable policies on fuel consumption calculation, internal combustion engine (ICE) vehicles will dominate the market in the short term. Therefore, the energy efficiency potential of ICE vehicles is crucial for the target achievement. In this article, a forecast on the fuel consumption reduction potential of domestic passenger vehicles (excluding NEV) will be made based on PSFI analysis and ERFC index scenarios to evaluate the difficulty faced by the domestic companies in achieving the energy efficiency target.

2. PSFI and ERFC index
The progress made in automotive technologies has led to changes in vehicle properties. The improved engine and powertrain efficiency positively impact fuel consumption reduction, but increased curb weight and body size exert negative impacts [3]. Thus, how to evaluate fuel economy accurately has become an industrial focus. In the annual reports on Fuel Economy Trends released by EPA, Ton Mpg (miles per gallon) is adopted as an indicator to describe automotive efficiency [4]. However, the Ton Mpg only indicates vehicle conveying efficiency in regards to weight, not the compound effect of power matching and space change on fuel consumption. Hence it is necessary to introduce a complex indicator with comprehensive consideration of power, economy and space to evaluate the true development level of automotive energy efficiency technology.

Feng A and John D put forward the concept of PSFI for the first time [5], to evaluate U.S. passenger vehicle changes in properties including power, economy and space, and prove the
corresponding relationship between PSFI and technical progress in automotive industry. Cheah L W et al. then propose the concept of ERFC index \([6]\), to indicate the degree of fuel economy improvement contributed by technical progress, and forecast fuel economy trends of U.S. passenger vehicles by adopting this index.

The parameters for evaluating passenger vehicle energy efficiency vary between automotive industries in U.S. and in China. China usually use fuel consumption \((L/100km)\) as the unit while U.S. adopt fuel economy unit \((MPG)\). On this account, PSFI and ERFC index proposed by foreign researchers will be restructured in this article to make them applicable to the energy efficiency trend study of Chinese passenger vehicles. See the following formula:

\[
PSFI = \frac{P \cdot S}{F}
\]

\(P\) is engine power rating/curb weight, \(kW/kg\);
\(S\) is vehicle length * width * height, \(m^3\);
\(F\) is NEDC combined fuel consumption, \(L/100km\).

By calculating average PSFI, the progress speed and development level of vehicles, regarding power, space and fuel consumption for a period can be analyzed. An evaluation of the fuel consumption reduction potential can be gained by a further analysis on PSFI. The fuel consumption reduction potential refers to the resulting fuel consumption after all technical progress is contributed to fuel consumption reduction, assuming the power and space remains the same as the base year. See the formula:

\[
FC_{potential} = \frac{(P \cdot S)_{base}}{PSFI_{cal}}
\]

\(FC_{potential}\) is fuel consumption reduction potential of the applicable year, \(L/100km\);
\((P \cdot S)_{base}\) is the power and space of the base year;
\(PSFI_{cal}\) is the PSFI value of the applicable year.

Based on the fuel consumption reduction potential, we can further introduce ERFC index to indicate the degree of consumption made by technical progress. See the following formula \([7]\):

\[
ERFC = \frac{FC_{base} - FC_{cal}}{FC_{base} - FC_{potential}}
\]

\(FC_{base}\) is the actual fuel consumption of the base year, \(L/100km\);
\(FC_{cal}\) is the actual fuel consumption of the applicable year, \(L/100km\);
\(FC_{potential}\) is the fuel consumption reduction potential of the applicable year, \(L/100km\).

Based on ERFC index, the degree of technical progress contributed to the fuel consumption reduction can be observed, and the fuel consumption reduction potential can be gained by evaluating future ERFC index.

3. PSFI and ERFC index analysis on domestic passenger vehicles

PSFI trends of domestic passenger vehicles (hereinafter, excluding NEV) can be calculated by the domestic passenger vehicle data including fuel consumption, curb weight, engine power rating and space from 2009 to 2015 (Data Source: MIIT fuel consumption data management system). In figure 1, PSFI uptrends of vehicles manufactured by both joint ventures and local companies could be observed. A good linear relationship could also be found, indicating an upward trend of overall technical level of domestic passenger vehicles. During the period between 2009 and 2015, PSFI value of local passenger vehicles were 19.8% lower than those of vehicles manufactured by joint ventures, but the former grew faster than the latter, indicating a narrowing gap between properties of local vehicles and of joint venture brand vehicles.
Figure 1. 2009-2015 average PSFI changes of domestic passenger vehicles

Figure 2 indicates ERFC index changes of domestic passenger vehicles. In 2010, ERFC indexes of two vehicle groups were almost the same, showing that only 23% of technical progress were contributed to fuel consumption reduction. However, joint ventures and local companies adopted different attitudes after the release of Fuel Consumption Evaluation Methods and Targets for Passenger Cars (Phase III) in 2011. Joint ventures have attached greater importance to fuel consumption. Nevertheless, local companies had a late start in the industry. Due to the relative backwardness in power and space, local companies choose to prioritize the power and space development instead of the fuel consumption reduction to ensure their market competitiveness. As a result, the average ERFC index of local passenger vehicles from 2012 to 2015 was only 6.7%, and the fuel consumption even experienced an increase between 2014 and 2015.

Figure 2. 2010-2015 average ERFC index changes of domestic passenger vehicles

4. An analysis on the fuel consumption reduction potential of Domestic passenger vehicles

As shown in the figure 3, the future fuel consumption reduction potential can be evaluated by observing PSFI and ERFC index development trends of domestic passenger vehicles. PSFI usually presents a good linear relationship according to the historical trends. Accordingly, if we perform linear
fitting on past PSFI and extend the trend line, we can forecast PSFI changes of domestic passenger vehicles between 2016 and 2020.

![Graph](image)

**Figure 3.** Forecast on average PSFI changes of China’s passenger vehicles

As shown in the table 1, it is estimated that in 2020, PSFI of passenger vehicles manufactured by joint ventures will reach 0.1649, at growth rate of 21.4% compared with PSFI in 2015. PSFI of local passenger vehicles will be 0.1667, increased by 34.0% compared with the number in 2015. Therefore, it is expected that the power, economy and space of local passenger vehicles will reach the same development level as joint ventures in 2020.

| PSFI Forecast                  | 2016 | 2017 | 2018 | 2019 | 2020 |
|-------------------------------|------|------|------|------|------|
| Joint Venture Passenger Vehicles | 0.1449 | 0.1499 | 0.1549 | 0.1599 | 0.1649 |
| Local Passenger Vehicles      | 0.1375 | 0.1448 | 0.1521 | 0.1594 | 0.1667 |

Due to the intensive fluctuations on annual ERFC index and other influencing factors such as policies and market, it is difficult to find a fixed rule to forecast ERFC index. Thus in this article, scenario analysis will be employed by assuming ERFC index based on certain scenario setting principles. Scenario setting principles are shown as follows: 1) From 2016, China has entered the fourth phase of fuel consumption control, and the fuel consumption target is further tightened by 30% compared with phase III, which means in the period from 2016 to 2020, companies need to reach a higher ERFC index level than the average index level between 2012 and 2015. 2) According to the development trend of domestic passenger vehicle market, power and comfortability remain to be top concerns for consumers in the near future. As a result, ERFC index of all passenger vehicles must be kept below 100% to ensure market competitiveness. 3) Compared with passenger vehicles manufactured by joint ventures, local ones should pay more attention to improving the power and space. In addition, a majority of local companies rely on NEV production to meet the fuel consumption target, so ERFC index of local vehicles should be 30% lower than that of joint venture vehicles. Based on these principles, average ERFC indexes of domestic passenger vehicles between 2016 and 2020 are set under two scenarios in table 2. In the low scenario, ERFC indexes of joint venture vehicle brands and local vehicle brands are 75% and 40% respectively; in the high scenario, ERFC indexes are 90% and 60% respectively.
The fuel consumption reduction potential can be calculated based on PSFI and ERFC index from 2016 to 2020 and domestic passenger vehicle parameters in 2015. In low ERFC index scenario, companies contribute most technical capacity in the power and space improvement but pay less attention to fuel economy. The corresponding fuel consumption levels of joint venture vehicles, local vehicles and the overall domestic vehicles between 2016 and 2020 are shown in table 3. In this scenario, the fuel consumption of domestic vehicles will be reduced to around 6.11L/100km in 2020, and can only reach 5.53L/100km even if taking NEV into account (calculated with a NEV yield of 1.4 million, 62% of EV and 38% of PHEV in 2020), which is much higher than the 5L/100km target in 2020.

### Table 2. 2016-2020 Average ERFC index scenario settings of China’s passenger vehicles.

| ERFC index          | Low Scenario | High Scenario |
|---------------------|--------------|---------------|
| Joint Venture Vehicles | 75%          | 90%           |
| Local Passenger Vehicles | 40%          | 60%           |

### Table 3. 2016-2020 Forecast on the fuel consumption reduction potential of domestic passenger vehicles in low ERFC index scenario (L/100km).

| Year | 2016 | 2017 | 2018 | 2019 | 2020 |
|------|------|------|------|------|------|
| Joint Venture | 6.60 | 6.43 | 6.28 | 6.14 | 6.01 |
| Local | 6.75 | 6.62 | 6.51 | 6.40 | 6.31 |
| Domestic | 6.64 | 6.49 | 6.36 | 6.23 | 6.11 |

In high ERFC index scenario, companies attach great importance to the fuel consumption and contribute as much technical progress to fuel consumption reduction as possible. The corresponding fuel consumption levels of joint venture vehicles, local vehicles and the overall domestic vehicles from 2016 to 2020 are shown in table 4. It can be observed that if companies make most contribution to reduce fuel consumption, the fuel consumption level of domestic vehicles can only be lowered to 5.87L/100km. Even if taking NEV into account, the number can only be reduced to 5.31L/100km (calculated with a NEV yield of 1.4 million, 62% of EV and 38% of PHEV in 2020), which still fails to reach the 5L/100km target in 2020.

### Table 4. 2016-2020 Forecast on the fuel consumption reduction potential of domestic passenger vehicles in high ERFC index scenario (L/100km).

| Year | 2016 | 2017 | 2018 | 2019 | 2020 |
|------|------|------|------|------|------|
| Joint Venture | 6.53 | 6.34 | 6.15 | 5.98 | 5.82 |
| Local | 6.62 | 6.43 | 6.25 | 6.10 | 5.95 |
| Domestic | 6.56 | 6.37 | 6.19 | 6.02 | 5.87 |

### 5. Conclusion

In this article, an analysis is performed on PSFI development trends of joint venture passenger vehicles and local passenger vehicles, and a forecast of the fuel consumption reduction potential of domestic passenger vehicles is conducted based on different ERFC index scenario assumptions. The study shows that with current technological speed, even if companies contribute most technical progress to the fuel consumption reduction, the fuel consumption level of domestic passenger vehicles can only be reduced to 5.87L/100km in 2020. Even if new energy vehicles are taken into account, the
level will only be lowered to 5.31L/100km, showing a certain gap from the 5L/100km target in 2020. Chinese manufacturers can only achieve the Phase IV target by approaches as follows:

- 1. Increase technology research and development investment and accelerate vehicle property development, which means a higher PSFI growth rate.
- 2. Sacrifice part of the power and comfortability to achieve further reduction of fuel consumption.
- 3. Increase new energy vehicle output to compensate negative impacts caused by the insufficient energy efficiency potential of ICE vehicles.

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