CHINA CAFE POLICY MIX: THE TECHNOLOGICAL TRADE-OFFS AND PROGRESS, COMPLIANCE FEASIBILITY AND WELFARE ANALYSIS

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ABSTRACT

CAFE standards have become a widely-adopted policy for improving fuel economy around the world. Following many developed countries, China enacted its first CAFE standards in 2004. Since then, a series of CAFE standards and CAFE related policies came into force in China, coinciding with the growing awareness of the importance of fuel economy from government, academia, media and consumers. The previous literature on China CAFE standards is inadequate. This thesis provides a clear and comprehensive picture of the China's entire CAFE policy mix. It also estimates the technology trade-offs and the technology progress for passenger vehicles sold in China, and the willingness-to-pay (WTP) of Chinese consumers for fuel economy, weight and engine power. Furthermore, it unveils the underlying stories of China's past improvements in fuel economy, predicts its future compliance feasibility, and calculates welfare benefits and losses of implementing CAFE standards in China.

BIOGRAPHICAL SKETCH

Jing He graduated from Fudan University (in Shanghai, China) with a Bachelor of Economics degree in International Economics and Trade from Department of World Economics, School of Economics in June 2011. Following his completion of an undergraduate degree, Mr. He was admitted to the graduate school at Boston University and was conferred a Master of Arts degree in Economics in May 2012. Immediately after graduating from Boston University, Mr. He joined Charles H. Dyson School of Applied Economics and Management at Cornell University, focusing on resources economics.

My thesis is dedicated to my parents, Rongding He and Huiqing Wu. Without their support, I would not have completed this graduate degree.

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Chapter 1 Introduction

Backgrounds and the Focus of the Thesis

Human beings are faced with a serious threat to sustainable development, the increasing concentration of greenhouse gas (GHG) in the atmosphere. The 'turning point' of concentration level is estimated to be the double of that in 18th century, the pre-Industrial Revolution era. If earth's CO_2 concentration level exceeds that threshold, then some truly dangerous consequences would happen, such as the disappearance of Greenland's ice cap (Socolow and Pacala, 2006). In 2006, Socolow and Pacala estimated that if emission rate of CO_2 continues to grow from 2006 for the next 50 years at the average pace of the past 30 years, then even the world takes real efforts to decarbonize, the concentration level will unavoidably triple from the pre-Industrial level (Socolow and Pacala, 2006). So, the only thing we can do to prevent this disaster is to significantly reduce the amount of CO_2 released into the air immediately.

A significant amount of energy-related GHG emissions is attributed to the transportation sector. According to U.S. Energy Information Administration (US EIA), in 2010 about 26 percent of delivered energy consumption in the world is attributed to the transportation sector, and energy demands from this sector are projected to grow by 1.1 percent from 2010 to 2040, largely due to the growth in non-OECD countries (US EIA, 2013).

The biggest demands in transportation sector come from the road transports, which account for 81 percent of energy use in this sector (Atabani et al., 2011). Furthermore, its share is expected to rise as automotive markets are growing rapidly in developing countries. Thus, two important implications can be inferred: 1) there are considerable potentials for the transportation sector, especially the road transports, to contribute to the 'battle' against global warming, and 2) developing countries will play more and more important roles in reducing GHG emissions.

Among all types of vehicles in the road transports, this thesis focuses on the 4-wheel passenger vehicles and 4-wheel commercial vehicles, the two major sectors in the road transports. According to Fuel Economy and Environmental Impact (FEEI) model developed by Huo and Wang (Huo and Wang, 2012), there are three important factors to determine the level of CO_2 emissions related to the road transports. The first factor is the total amount of vehicle stocks around the world. The second factor is how intense people use their vehicles (kilometers or miles traveled per vehicle per year). The third one is vehicle energy-use efficiency (i.e. fuel economy). Assuming that all types of fuel have the same level of carbon contents[1] and the fuel is fully burned, the amount of CO_2 emissions would be proportional to the multiplication of these three factors.

It is obvious that all the three factors are equally important. Most policy tools are designed to affect one of the three factors, but typically also have indirect effects on the other two. Examples are CAFE standards, gasoline taxes, pollutants emission standards, highway tolls, vehicle purchase taxes, hybrid/electric technology subsidies in production and/or purchase. To summarize, Table 1 provides a comparison of how these policy tools may affect these three factors.

This thesis focuses on the CAFE standards[2] and CAFE related[3] policies, and the new vehicles market for 4-wheel passenger vehicles and 4-wheel commercial vehicles. For the rest of the thesis, I use 'CAFE policy mix' to refer to CAFE standards and CAFE related policies, and 'CAFE standards' to refer to CAFE standards alone.

Fuel economy can be considered as a characteristic of a vehicle. Three most common ways to measure fuel economy are 1) how much distance a vehicle can move given a fixed amount of fuel, 2) how much fuel a vehicle needs given a fixed amount of distance to move, and 3) how much CO_2 is released given a

[1] Rigorously, this does not hold. For example, gasoline and diesel, two types of commonly used fuel, have different carbon contents.
[2] 'CAFE' stands for 'Corporate Average Fuel Economy', and reads as café. Note that, in this thesis, I use the term 'CAFE' in a broader sense to include those policies which do not regulate on a corporate average basis, such as 'China Passenger Cars CAFE Standards Phase I'.
[3] For CAFE related policies, I refer to those policies related to CAFE standards, including fuel economy testing methods, fuel economy labeling standards ('window sticker') and fuel economy disclosure policies.

vehicle moving for a fixed amount of distance. Although different countries and regions use different types of measurement, it is easy to convert one to another by simple calculations. For example, US measures fuel economy in ‘miles per gallon’ or ‘MPG’, while China measures it in ‘liters per 100 kilometers’ or ‘L/100 km’. To convert ‘liters per 100 kilometers’ to ‘miles per gallon’, we simply multiply the reciprocal of the MPG number by 235.24 (=100/1.609*3.785). If fuel economy is measured similar to US’s way, then it is usually referred as ‘fuel economy’. If it is measured similar to China’s way, then it is usually referred as ‘fuel consumption’. The choice of measurement types conforms to the commonly accepted practices in the country. In the previous example, ‘mile’ is commonly used in US as ‘kilometer’ in China.

Motivations, Purposes and the Structure of the Thesis

The main motivation of this thesis is that China adopted Passenger Cars CAFE Standards Phase III in 2012. It is a milestone in China’s CAFE regulation practices since it is the first time China regulates its automotive industry on the corporate average level, instead of on the model level with maximum limits as in phase I and phase II of the passenger cars CAFE standards.

Another motivation is that data gradually becomes available to the public. Data on fuel economy became available after Ministry of Industry and Information Technology of China (China MIIT) established the first publicly accessible fuel consumption database in 2010 (http://gzly.miit.gov.cn:8090/datainfo/miit/babs2.jsp), which contains data on fuel consumption levels of vehicles sold in Chinese automotive market[4].

[4] This database is the origin of fuel consumption data of vehicles sold in China, partially on which many consulting firms and media companies construct their own databases. In the empirical study of this thesis, I don’t directly use the China MIIT database, but the ultimate source of the fuel consumption data I use is from it.

The third motivation is that the academic research, in particular English studies, on China's CAFE policy mix is inadequate. Due to the language barrier[5], it is not easy for non-Chinese-speaking researchers to gather information on China's CAFE policy mix. Also, among the limited research on China's CAFE regulations, most of it is from an environmental engineering perspective, not from an economics perspective.

This thesis is motivated by the above three initiatives and aims to serve two purposes as follows. The first purpose is to provide readers with a clear and comprehensive picture of China's entire CAFE policy mix. The policy analysis is quite comprehensive for 1) that it covers all the passenger car, LDCV and HDCV segments, 2) that it discusses all of China's CAFE standards, testing methods, labeling standards and disclosure policies, and 3) that it explains in details the underlying motivations, development, structures and rules of China's CAFE standards.

The second purpose is to utilize the data on fuel economy and monthly sales volumes 1) to estimate the technology trade-offs between fuel consumption, weight, torque and engine power (also known as the 'technology frontier'), 2) to estimate the technology progress over time, 3) to unveil the underlying stories of China's past improvements in fuel economy and where it could possibly head in the future, using the estimates of the technology trade-offs and the technology progress, and 4) to estimate the willingness-to-pay (WTP) for fuel economy, weight and engine power in China, and then to calculate the welfare benefits and losses for improving fuel economy.

The reminder of the thesis is organized as follows. Chapter II discusses the development of CAFE policy mix around the world, with an emphasis on US CAFE standards. Chapter III discusses the China's CAFE policy mix in details, makes a comparison between China and US in CAFE standards and summarizes the academic studies on China's CAFE policy mix. Chapter IV discusses the data I use in the empirical study in Chapter V, VI and VII. In Chapter V, VI and VII, I utilize the data to estimate the technology trade-offs

[5] The majority of the official documents issued by Chinese government on China's CAFE policy mix are written in Chinese, with no official English translations.

and the technology progress (Chapter V), to understand China's past and future situations in fuel economy in the context of the technology trade-offs and the technology progress (Chapter VI), and to calculate the welfare benefits and losses of improving fuel economy in China (Chapter VII). Finally, Chapter VIII makes the conclusion.

Chapter 2 CAFE Policy Mix around the World

United States Enacted the First CAFE Standards in the World ('US CAFE Standards Phase I')

As a huge breakthrough, US became the first country in the world to adopt CAFE standards in 1975. The congress passed the 'Energy Policy and Conservation Act' to enact Corporate Average Fuel Economy (CAFE) standards. When CAFE standards were first established in US, the intent of the policy maker was to reduce US's dependence on imported oil from the Middle East, a lesson US learned from the 1973-1974 oil crisis. But, now the concerns about the global warming become the main motivation underlying the ongoing development and reforms of CAFE standards in many countries around the world (including US).

US CAFE standards are defined as "sales weighted average fuel economy, expressed in miles per gallon, of a manufacturer's fleet of passenger cars or light trucks with a gross vehicle weight rating of 8,500 lbs or less, manufactured for sales in the United States, for any model year" (Steiner and Mauzerall, 2006). The CAFE standards only apply to new vehicles sold in each model year, so it will take many years before it could fully exert its influences on the overall fuel economy level of the country's whole fleet.

For each model year (MY), every manufacturer is required to calculate three sales-weighted averages for domestic cars, imported cars and light trucks. Each averaged number is required to meet its own target. Domestic cars and imported cars are subject to a single target for passenger cars, and light trucks are subject to another target for light trucks (Steiner and Mauzerall, 2006). If a car has more than 50 percent of its total components manufactured in the United States, it is classified as a domestic car. Otherwise it is classified as an imported car (Steiner and Mauzerall, 2006). The exact and detailed definitions to distinguish a passenger car from a light truck is beyond the scope of this thesis, but roughly SUVs, minivans and pickups are classified as light trucks while sedans, coupes and sports cars are classified as passenger cars. The targets for light trucks are less strict than those for passenger cars, so the manufacturers always have the incentives to classify a model as a light truck.

The passenger cars standards require manufacturers to meet for their passenger cars the target of 18 MPG in MY 1975 and 27.5 MPG in MY 1985, with the MPG targets creeping up in between. The CAFE standards are quite strict to some extent, since manufacturers actually responded to the CAFE standards by seriously 'downsizing' in weight, horsepower and torque. The regulator have some flexibility in implementing the standards. "The secretary of transportation has the discretion to adjust the passenger car standard within a range of 26-27.5 mpg". (Klier and Linn, 2011) The light trucks standards took effects in MY 1979 with a target of 17.2 MPG, and the target rose up quickly in the following years. However, these two sets of standards have changed little since MY 1985[6] (Klier and Linn, 2011). In MY 2009, the targets for passenger cars and light trucks are 27.5 MPG and 23.1 MPG, respectively (Klier and Linn, 2011).

To minimize the costs of improving fuel economy, the CAFE standards allow firms to earn credits for over-compliance so that they can use them for future years. However, the transfer of credits is limited within the firm and credits are not allowed to be transferred across passenger car segment and light truck segment (Klier and Linn, 2011).

The non-compliance comes with penalties. At the start of the establishment of CAFE standards, for every vehicle sold and for every 0.1 MPG below the targets, the manufacturer should pay a fine of $5.00. For example, if GM sold 1 million light trucks in US and its corporate sales-weighted average fuel economy for light trucks miss the target by 2 MPG, then GM need to pay $10 million (2 MPG * $5.00 * 1 million units) for that model year. The penalty rate increased to $5.50 in 1997 (Klier and Linn, 2011). In the past several decades, the Japanese manufacturers were significantly above the standards, the US manufacturers struggled to be marginally above the standards[7] and the European manufacturers just considered the fines as a type of costs for selling their gas-guzzling cars in US (Portney et al., 2003; Steiner and Mauzerall,

[6] The exception is that the light trucks standards crept up slowly in the 2000s.
[7] However, the de facto 'fines' these US manufacturers paid for CAFE could be higher if we consider the costs of lobbying as a special type of 'fines'. The fact that they struggled to meet the standards may render that they lobby more than other manufacturers.

2006). The total CAFE fines received between 1983 and 2003 amounted to more than $600 million (Klier and Linn, 2001).

Whether the CAFE standards had direct effects on the improvements of fuel economy after they were enacted remains an open question[8]. However, the undeniable fact is that after the CAFE standards were established, the actual fuel economy doubled between mid-1970s and mid-1980s (Klier and Linn, 2011). After that period, the actual fuel economy deteriorated slowly due to the fact that the light truck segment was gaining market share and light trucks are subject to less strict targets. These also coincided with the fact that both passenger cars and light trucks standards remained almost flat after MY 1985.

After CAFE standards were established in the United States, huge amounts of academic attentions have been attracted to analyze various aspects of CAFE standards. Topics include the costs of compliance with CAFE standards[9], the comparisons between CAFE standards and other alternative policy tools (such as gasoline taxes), the rebound effects of CAFE standards, safety concerns, dynamics of the technology frontier and credit transfer market. For a more detailed overview of literature on US CAFE standards, please see Klier and Linn (2011).

United States CAFE Standards Phase II

After MY 1985, the CAFE standards became stagnant. There were a lot of debates over whether or not the original CAFE standards need to be reformed and/or to be replaced by another phase of CAFE standards. The major drawback of the original CAFE standards is that they fail to improve the overall fuel economy of US fleet after MY 1985. According to Steiner and Mauzerall (2006), three factors underlie the inability of CAFE standards. Firstly, as personal income and population increase, Americans tend to buy more cars and drive more. Secondly, although National Highway Traffic Safety Administration

[8] It is entirely possible that the soaring oil price in the mid- and late-1970s also contributed to the improvements in fuel economy.
[9] This type of research can be further divided into short-run, medium-run and long-run. See Klier and Linn (2012) for details.

(NHTSA) has some authority to tighten the CAFE standards, they are faced with pressure from the Congress. Thirdly, as mentioned before, the increasingly larger share of the low-MPG light truck segment is detrimental to the overall fuel economy of whole US fleet. Fourthly, customers are myopic and fail to fully incorporate into their purchasing decisions the fuel savings from more fuel-efficient vehicles.

Some researchers and politicians are in support of the reform. In 2001, a study was conducted by National Research Council (NRC) under the support of National Academy of Sciences. The study advocated the expansion of the CAFE standards and suggests a 40 percent improvement in fuel economy for the next 10 to 15 years (NRC, 2002). In 2005, Senator Obama made a proposal that the government absorb part of the automotive industry's retiree health costs while in turn the manufacturers should invest half of the subsidies into R&D of hybrid technologies. Steiner and Mauzerall (2006) raised a combined solution for reducing GHG which includes CAFE reforms as one component in their four-policy suggestion. In August 2005, NHTSA proposed a notice of rulemaking concerning the light trucks[10] beginning at MY 2008 (Bamberger, 2006).

On the other side, opponents argued that the costs of a second-phase CAFE program would be huge compared to its benefits, and that some market-based policy tools are more efficient to achieve the same goal (Klier and Linn, 2011). For example, Portney et al. pointed out that the social costs of CAFE standards are huge after taking into account the existing fuel taxes, rebound effects and safety concerns, though fuel combustions have many negative externalities (Portney et al., 2003). The congress also showed low interests in tightening CAFE standards, probably due to the lobbying by the oil and automotive industries (Steiner and Mauzerall, 2006).

Despite the reluctance of legislators and heated debate over the costs and benefits, the Phase II CAFE standards finally came into force. Under the Bush administration era, the passage of 'The Energy Independence and Security Act' of 2007 established the Phase II CAFE standards. Roughly speaking, the

[10] More accurately, this proposal is concerned with SUVs and enacts higher standards based on vehicle size.

new standards increase the fuel economy targets by 40 percent. They began to phase in with MY 2011 and the targets will reach 35 MPG by MY 2020. The Obama administration further tightened the Phase II CAFE standards with a target of 35.5 MPG by MY 2016.

There are several important new features of the Phase II CAFE standards. Firstly, US CAFE regulations for the first time regulate the GHG emissions by vehicles (Yacobucci, 2010). Secondly, the new standards introduce the concept of 'footprint', which is defined by the rectangle created by the vehicle's four wheels. A vehicle with a smaller footprint is subject to a lower MPG. Then, the average fuel economy target for a manufacturer is calculated as the sales-weighted average of the fuel economy target for each vehicle model. (i.e. for each MY, the target for each manufacturer is different, and it is a moving target depending on the fuel economy targets of the models it produces and the number of units each model is sold) Thirdly, under the new standards, credits transfer is not limited within a firm and credits are allowed to be transferred across passenger car segment and light truck segment. An inter-firm credit transfer market could be established to allow credit transfers across the boundaries of manufacturers. The intent of it is to minimize the compliance costs of CAFE standards.

CAFE Policy Mix around the World

Subsequent to the US CAFE standards enacted in 1975, many countries established their own CAFE policy mix. Canadians followed Americans' steps most closely. In 1976, Canada established its CAFE regulations by introducing Canada Company Average Fuel Consumption (Canada CAFC), but the implementation was on a voluntary basis until a 1982 legislation to made it into a mandate (An and Sauer, 2004). The European Union also established its own standards. In March 1998, the European automobile manufacturers association and its members signed a voluntary agreement with the European Commission to reduce CO_2 emission rates of vehicles sold in European Union (An and Sauer, 2004). Other developed countries and regions, such as Australia, California, Japan and South Korea, also established similar regulations. In 2004, China also joined in them and released its own carefully-designed CAFE policy mix.

This move attracted a lot of attentions and won applauses around the world since China is the first developing country to establish the CAFE standards (Oliver et al., 2009). I will discuss the development of China's CAFE policy mix in details in the next section. After China's move, other developing countries, such as Brazil, Indonesia and Mexico, also enacted their own voluntary or mandatory CAFE standards over the past decade.

Although a complete analysis and comparison of different CAFE standards is beyond the scope of this thesis, several interesting features are worth mentioning. Firstly, many CAFE standards outside US were initially established as voluntary standards. But, most countries switched to mandatory standards recently as voluntary standards have often fallen short of targets (Onoda, 2008). This is understandable because voluntary standards offer few incentives for manufacturers to improve fuel economy. Secondly, although some countries and regions, such as EU and Japan, enacted their CAFE standards subsequent to US, their CAFE standards are much stricter than US CAFE standards. Even China's CAFE standards are stricter than the US ones though they are enacted almost 30 years later than the US ones (ICCT, 2014a). Thirdly, probably due to the second-mover advantage, some countries, such as Japan and China, have a better structure in their CAFE standards. The original US CAFE standards treat all models in the passenger car segment or in the light truck segment as the same. As a result, the safety concerns arise since CAFE standards might cause the problem of the serious 'downsizing' of the fleet, in terms of vehicle weight and engine power (Crandall and Graham, 1989; Portney et al., 2003). Also, the welfare losses due to the decrease in horsepower are estimated to be huge compared to fuel savings from fuel economy improvements (Klier and Linn, 2013). China's passenger cars CAFE standards, for example, could alleviate such concerns since different fuel economy targets are assigned to different models based on their curb weight class (SAC, 2004). The US CAFE standards actually incorporated this feature into its Phase II regulations, as discussed above.

CAFE standards in different countries differ in various aspects. One of major differences is already mentioned above, i.e. the difference in measurement of fuel economy. Also, testing methods vary across countries, due to the differences in road conditions and driving patterns in different countries. Thus, to compare the structure and, more importantly, the stringency of CAFE standards in different countries, a systematic conversion methodology is needed. Furthermore, since countries typically reformed and tightened their CAFE standards every a few years, such a comparison study needs to be updated from time to time.

The first attempt to comprehensively compare different versions of CAFE standards was made by two researchers from Pew Center on Global Climate Change. In 2004, An and Sauer wrote a groundbreaking report on the comparison of CAFE standards around the world (An and Sauer, 2004). “They proposed a methodology for directly comparing vehicle standards defined in terms of grams of CO_2 per kilometer (as in the EU) and miles per gallon (as in the U.S.).” (ICCT, 2014b) In 2007, ICCT released an update on the 2004 Pew Center report by refining the original methodology and incorporating the important changes in CAFE standards in EU, Japan and US (ICCT, 2007). After that, ICCT keeps updating the comparison study every a few years. The most recent update is the 2014 update (ICCT, 2014a).

There is also a study done by Atabani et al. (2011) on the comparison of CAFE related policies in different countries and regions. They analyzed CAFE standards and testing methods in US, EU, Japan, California and China, as well as labeling policies in over 10 countries and regions.

Some research focuses on a single country, or on a two-country comparison. Examples include but not limited to: Sheinbaum-Pardo and Chávez-Baeza (2011) analyzed the fuel economy trends in Mexico over the period from 1988 to 2008. Mahlia et al. (2010) discussed the implementation possibilities of CAFE standards in Malaysia. Silitonga et al. (2012) compared the CAFE standards and labeling policies in six ASEAN countries. Atabani et al. (2012) conducted a cost-benefit study of CAFE standards for passenger cars in Indonesia.

Although CAFE standards have already been established by policy makers in many countries, the academic discussions are unevenly distributed towards US. Not much research is done for those non-US

CAFE standards, compared with a large number of papers discussing US CAFE standards in the past several decades. However, non-US CAFE standards also need academic attentions for at least two reasons: Firstly, it does not matter whether it is in the US, China, Japan or Europe that CO_2 is released. Secondly, the CAFE standards around the world keep developing and now they are far more complicated than the original US CAFE standards. The original US CAFE standards now look like a plain-vanilla version compared with the ongoing reforms of CAFE standards in other countries and regions. Although US also reformed by enacting the phase II CAFE standards, there are still a lot of things that US can learn from other countries' CAFE regulation practices.

Chapter 3 China's CAFE Policy Mix

China's Motivations of the Establishment of its CAFE Regulations

Oliver et al. (2009) summarize three motivations underlying China's implementation of its own CAFE standards. Firstly, similar to US's initial intent when Americans enacted the first CAFE standards in the world, the Chinese government is also concerned with China's increasing dependence on imported oil. According to He et al. (2005), following US and Japan, China has already been the third largest oil consumer by the end of 20th century. However, China's domestic oil production cannot support its growing oil-guzzling economy. As a result, beginning in 1993, China became a net oil importer. In 2011, China's imported oil has reached 316 million tons, which accounted for 70 percent of its total oil consumption in that year (China Statistical Yearbook, 2013).

China's official disclosure on total energy consumption by transportation sector is not available. However, it is estimated that, in 2003, 17 percent of China's total energy consumption is attributed to its transportation sector (Knörr and Dünnebeil, 2008). By comparison, the share in Europe is about 27 percent (Knörr and Dünnebeil, 2008). Since Chinese automotive industry grows at a higher speed than China's GDP after 2003, it is reasonable to believe that China's transportation sector now accounts for a even larger share of its total energy consumption. Also, a report by International Energy Agency (IEA) indicated that, in 2005, the transportation sector accounted for 37 percent[11] of China's total oil consumption, and the road transports accounted for 25 percent out of this 37 percent (IEA, 2007).

These daunting facts as well as the increasing international pressure caught attentions of Chinese government. CAFE policy mix has the advantage of directly regulating the fuel economy of the new vehicle market. Also, practices in US have already showed the effectiveness of CAFE standards in

[11] The huge difference in the share estimation by Knörr and Dünnebeil (2008) and IEA (2007) might be largely explained by that 'energy' contains 'oil' as a subset.

improving the fuel economy and pushing innovations in fuel-efficient technologies. These facts strengthened the confidence of Chinese government to adopt its own CAFE policy mix.

Secondly, the join-venture dominated automotive industry in China also creates a unique motivation for Chinese government to implement CAFE standards (Oliver et al., 2009). After China opened up its automotive industry to foreign companies in the mid-1980s, almost all the major automotive groups in the world gradually entered Chinese market and established joint ventures with local Chinese automotive manufacturers[12]. Partly[13] because these foreign auto makers are reluctant to share the cutting-edge technologies with their Chinese local partners, it is common for joint ventures to sell outdated models. As a result, the fuel economy technologies used in Chinese fleet significantly lagged behind those in the developed markets. A study in 2003 by China Automotive Research and Technology Center (CATARC[14]) estimated that the average fuel economy of the new Chinese vehicles is 10 percent worse than those in Japan and Germany, while the average curb weight and average engine displacement are 11 percent and 15 percent less, respectively (Oliver et al., 2009; CATARC, 2003). Chinese government thought that the establishment of CAFE standards could provide Chinese local automotive manufacturers with more bargaining power as they negotiate the terms with their foreign joint-venture partners.

Possibly partly due to China's CAFE regulations, now the technology gaps between developed markets and Chinese market are already hard to detect or even disappear. For example, the latest generation of Chevrolet Malibu (8th generation) is first unveiled in 2011 in Auto Shanghai, a major auto show in China. China is also the second market in which the 8th generation Malibu is available for sales. Global manufacturers also place more and more emphasis on Chinese market to grab more shares in this largest

[12] Joint ventures are established typically on a 50-50 ownership structure. This is required by Chinese government, and has not been changed since it began.
[13] Other reasons might include 1) that Chinese automobiles buyers lack sophisticated knowledge in automobiles and information about the cutting-edge technology available in the global market, and 2) that automobiles are luxuries and only a few wealthy people could buy. Thus, even outdated models are considered as new and advanced products in China. But, situations have changed so that these are no longer the case now.
[14] CATARC is a semi-official research center. It is in charge of drafting China's CAFE standards and CAFE related policies.

automotive market in the world. It is not clear how much the CAFE standards contribute to narrow the technology gaps, but they are possibly one of the major driving forces.

The third motivation is to “push domestic manufacturers to improve” (Oliver et al., 2009). Besides co-production with their foreign partners through joint ventures, local Chinese automotive groups also produce automobiles under their own brands, such as SAIC’s Roewe, FAW’s Hongqi, DFMC’s Xiaokang, Chang’an Automotive Group’s Haval. There also exist some standalone Chinese automotive manufacturers which don’t establish joint ventures with foreign auto makers, such as Geely Group and Chery Group. However, limited by capabilities and technologies, these local brands focus on low-end markets and use outdated technologies. One of the objectives of China Passenger Cars CAFE Standards Phase I is to “eliminate backward products”. (Gao and Jin, 2011)

The Vehicle Classifications in China

Before I discuss China’s CAFE standards in details, it is worth explaining the official classifications of vehicles in China. Under Chinese laws on standard-making, the ultimate authority for creating, maintaining and publishing the national standards (i.e. “GB XXXX-XXXX” or “GB/T XXXX-XXXX”) is given to General Administration of Quality Supervision, Inspection and Quarantine (GAQSIQ). The Standardization Administration of China (SAC) is responsible for the actual administrative responsibilities, and is operated under the supervision of GAQSIQ (Oliver et al., 2009). The official classifications of vehicles in China are formalized into two national standards. These two national standards are “Motor Vehicles and Trailers Types--Terms and Definitions” and “Classification of Power-Driven Vehicles and Trailers”, indexed as “GB/T 3730.1-2001” (SAC, 2001a) and “GB/T 15089-2001” (SAC, 2001b) respectively. They are the foundations for the CAFE standards[15] I discuss below.

Table 2 summarizes and compares these two sets of classifications. Also, I match them with the segments used in the dataset for the empirical study of this thesis.

[15] China’s CAFE standards and CAFE related policies are also formalized into a series of national standards.

“GB/T 3730.1-2001” (SAC, 2001a) is the very foundation, which defines three categories, ‘Cars, ‘Trailers’ and ‘Combination Vehicles’. Though the latter two categories are not the focus of this thesis, I include them for the sake of completeness.

“GB/T 15089-2001” is based on “GB/T 3730.1-2001”. Table 2 is also structured in this way to reflect the fundamental importance of “GB/T 3730.1-2001”. Roughly speaking, ‘M’ category is for vehicles designed for transporting people, while ‘N’ category is for those designed for transporting goods. M_1 vehicles have 8 seats or less, while M_2 and M_3 vehicles have 9 seats or more. M_2 vehicles weigh less than 5,000 kg and M_3 vehicles weigh more than 5,000 kg. In the ‘N’ category, N_1 vehicles are defined as less than 3,500 kg, N_2 vehicles are between 3,500 kg and 12,000 kg and N_3 vehicles are more than 12,000 kg. ‘O’ category corresponds to ‘Trailers’ as defined in “GB/T 3730.1-2001”.

Furthermore, Table 2 also illustrates the distinctions between passenger cars (PCs), light-duty commercial vehicles (LDCVs) and heavy-duty commercial vehicles (HDCVs). ‘LDCVs’ and ‘HDCVs’ are not defined in the above two national standards but they are widely used in standard-setting and automotive industry. Roughly speaking, ‘light-duty’ means ‘less than 3,500 kg’ while ‘heavy-duty’ means ‘more than 3,500 kg’. The matching is shown in the third column of Table 2.

Finally, segments used in the empirical study of this thesis are matched with categories in the previous three sets of classifications. The segments I use in the empirical study conform to the common practices in Chinese automotive industry. ‘Mini’, ‘Small’, ‘Compact’, ‘Medium’, ‘Medium & Large’, ‘Luxury’ are also known as ‘A00’, ‘A0’, ‘A’, ‘B’, ‘C’ and ‘D’, respectively. These are segments commonly used in Chinese automotive industry mainly for segmentation in marketing. Examples for each segment are ‘Suzuki Alto’, ‘Ford Fiesta’, ‘Chevrolet Cruze’, ‘VW Passat’, ‘Audi A6L’ and ‘Porsche Panamera’, respectively. Similarly, ‘SUV’ is also further divided into several segments according to size. But, the empirical study in this thesis does not distinguish between them. ‘Sports’ refers to sports cars, such ‘Lamborghini Gallardo’ or ‘Porsche 911’. ‘Light Bus’ refers to vans. Most of the ‘Light Bus’ models in the samples of the empirical study fall into “M_2 vehicles ≤ 3,500 kg”, so I match ‘Light Bus’ with “M_2 vehicles ≤ 3,500 kg”[16]. ‘Pickup’, ‘Mini Truck’ and ‘Mini Van’ are considered mainly for transporting goods, so they fall into “N_1 vehicles” category.

To be precise, segments used in the empirical study of this thesis do not represent all vehicles in their associated categories. For example, “N_1 vehicles” category might include those which are not covered by the empirical study. However, the first three sets of classifications (i.e. first three columns in Table 2) can be completely mapped to each other according to Table 2.

The Development of China’s Entire CAFE Policy Mix

China’s CAFE policy mix can be divided into four components: CAFE standards, testing methods, labeling standards and disclosure policies. See Figure 1 for the structure of China’s entire CAFE policy mix. Table 3 provides a summary of CAFE standards and their associated testing methods, and Table 4 summarizes the labeling standards and the disclosure policies.

Almost every policy and every phase of it are formalized into national standards. The only two exceptions are disclosure policies and HDCVs CAFE Standards Phase I. The disclosure policies are not formalized in national or industry standards, and HDCVs CAFE Standards Phase I is formalized into “QC/T 924-2011”, an automotive industry standard.

The first two components are closely related to each other, so I discuss them together. Firstly, I discuss the CAFE standards for passenger cars in China. In September 2004, China started its CAFE regulations for passenger cars. The policy maker released “Limits of Fuel Consumption for Passenger Cars” or “GB 19578-2004” (SAC, 2004). It is also referred as “CAFE Phase I for M_1 vehicles ≤ 3,500 kg”. These standards regulate “M_1 vehicles ≤ 3,500 kg”, and are effective in mid-2005 for new models and in mid-2006 for old models. Since it is very rare that M_1 vehicles weigh over 3,500 kg, “GB 19578-2004” can

[16] Strictly speaking, a small portions of ‘Light Bus’ models included in the empirical study sample should be matched with “M_2 vehicles ≥ 3,500 kg” or “M_3 vehicles”, since they are heavier in weight.

also be considered as CAFE standards for regulating ‘Passenger Cars’ in China. For simplicity, I treat “M_1 vehicles ≤ 3,500 kg”, “M_1 vehicles” and ‘Passenger Cars’ as the same in the rest of this thesis.

According to a presentation by CARATC (Gao and Jin, 2011), the objective of the Passenger Cars CAFE Standards Phase I is to eliminate the backward passenger car models. Many of these inefficient models used the technologies from western countries back to the 1980s (Oliver et al., 2009). The policy maker hopes to accelerate the eliminations of these models and push foreign auto makers to bring to China more update-to-date technologies (Oliver et al., 2009). According to CARATC, Phase I successfully stopped production of over 400 backward models (Gao and Jin, 2011).

Passenger Cars CAFE Standards Phase II is formalized into the same national standard with Phase I[17], and thus it is released at the same time as Passenger Cars CAFE Standards Phase I. For both new and old models, Phase II standards are effective three years later than Phase I standards. Both Phase I and Phase II use the same testing methods, specified in the national standard “Measurement Methods of Fuel Consumption for Light-Duty Vehicles” or “GB/T 19233-2003” (SAC, 2003). Compared with the Phase I standards, the Phase II standards are more challenging for auto makers to meet and may require significant technology improvements and reconfigurations (Oliver et al., 2009).

Both Phase I and II standards are designed to be bottom-heavy, that is, more difficult for large-size vehicles to comply with. The reasons for that are mixed (Oliver et al., 2009). Firstly, the Chinese policy maker wants to control the growth of the SUV segment, possibly alarmed by the dominance of SUVs in US. Another reason is that they want to protect the domestic manufacturers which mainly produce the low-end and small-size vehicles.

[17] Of course, Phase I and II are totally different. The only thing in common is that they are released at the same time and are formalized into the same national standard.

The Phase II standards will still be in force for future years, even after Phase III standards are effective. The corporate-average approach[18] used in Phase III makes Phase II standards still useful to serve as the lower bounds for vehicle models to enter the market.

At the end of 2011, the widely-expected Phase III standards were released. The national standard for CAFE standards in Phase III is "Fuel Consumption Evaluation Methods and Targets for Passenger Cars" or "GB 27999-2011" (SAC, 2011a), while the national standard for testing methods in Phase III is "Measurement Methods of Fuel Consumption for Light-Duty Vehicles" or "GB/T 19233-2008" (SAC, 2008a). This is a milestone in the history of China's CAFE regulations, since for the first time China adopts a corporate-average approach instead of a model-level with maximum limits approach. I will discuss it in details below.

At this point of time, the Passenger Cars CAFE Standards Phase IV has not been finalized yet. It is expected that Phase IV will be fully effective in 2020, with a phase-in period before 2020. The objective of the Phase IV standards is to reduce the average fuel economy level of passenger cars to 5.0 L/100 km, according to an official notice released by The State Council of China (The State Council of China, 2012). Whether or not the testing methods in Phase IV will be the same as those used in Phase III is also not known.

Secondly, following CAFE regulations for passenger cars, China also released the CAFE standards and associated testing methods for light-duty commercial vehicles or LDCVs (i.e. "M_2 vehicles less than 3,500 kg" and "N_1 vehicles"). From Table 2, we can see that "M_2 vehicles less than 3,500 kg" and "N_1 vehicles" combined is referred as 'Light-Duty Commercial Vehicles' or 'LDCVs'.

Similar to the situations in Passenger Cars CAFE Standards Phase I & II, LDCVs CAFE Standards Phase I & II were also released together at mid-2007 and allow different effective dates for new and old models. These standards are formalized in the national standard "Limits of Fuel Consumption for Light Duty

[18] As discussed below.

Commercial Vehicle” or “GB 20997-2007” (SAC, 2007). Also, they use the same testing methods as those used in passenger cars CAFE regulations Phase I & II, that is, “Measurement Methods of Fuel Consumption for Light-Duty Vehicles” or “GB/T 19233-2003”. LDCVs Phase III CAFE regulations are currently under discussion and research. The widely-expected effective date of the Phase III CAFE standards is 2015.

Thirdly, CAFE regulations for heavy-duty commercial vehicles (or HDCVs) lag behind those for passenger cars and LDCVs. In China, “M_2 vehicles more than 3,500 kg”, “M_3 vehicles”, “N_2 vehicles” and “N_3 vehicles” combined is equivalent to ‘Heavy-Duty Commercial Vehicles’ or ‘HDCVs’. A presentation by CATARC (Zheng, 2013) argues that regulations for HDCVs are more important than those for passenger cars and LDCVs. HDCVs consumed half of total oil consumption of all vehicles in 2010 though they only accounted for the 10 percent of the total vehicle fleets in China.

A lot of research has been done before CATARC drafted the CAFE standards for HDCVs. They worked closely with the HDCV manufacturers and industry experts to figure out how strict the standards should be and how to design the testing methods. Since developed countries also just began to regulate the HDCV segments, the regulators in these countries don’t have many practical experiences to share with their Chinese peers. So, the design of HDCVs CAFE policy mix is far more difficult than before.

The two-phase structure is determined. The HDCVs CAFE Standards Phase I and its associated testing methods are formalized into an automotive industry standard “Fuel Consumption Limits for Heavy-Duty Commercial Vehicles” or “QC/T 924-2011” (China MIIT, 2011) and a national standard “Fuel Consumption Test Methods for Heavy-Duty Commercial Vehicles” or “GB/T 27840-2011” (SAC, 2011b), respectively. The draft version of HDCVs CAFE Standards Phase II is already available, which indicates that the Phase II effective dates would be mid-2014 for new models and mid-2015 for old models.

Finally, China also established the labeling standards and disclosure policies. Although these two policy tools are not necessary to implement CAFE standards, they are indispensable and important in the CAFE regulations. Labeling standards are formalized into “Fuel Consumption Label for Light Vehicle” or “GB 22757-2008” (SAC, 2008b), while disclosure policies are not subject to any national or industry standards. Currently, there two policies only apply to passenger cars and LDCVs. They started to be effective in 2010. Similar policies for heavy-duty vehicles are under discussions now. According to the labeling policies, manufacturers are required to place a sticker on the vehicle window, on which information about engine, weight, fuel type, transmission, fuel economy level and manufacturer is printed. The disclosure practices are jointly done by manufacturers and Chinese government. China MIIT established a database (http://gzly.miit.gov.cn:8090/datainfo/miit/babs2.jsp) on their website and the public could access it for free. It is updated every month to include the latest models available for sales in the market. By April 2013, there were more than 20,000 observations (with each representing a trim) included in the database.

The Structures and Features of ‘First Paradigm’ in China CAFE Standards

China started late, but it is moving fast and ambitiously. According to An and Sauer (2004), China Passenger Cars CAFE Standards Phase I ranks the third in terms of strictness, just after European Union and Japan but ahead of Australia, Canada and US.

Passenger Cars CAFE Standards Phase I & II, LDCV CAFE Standards Phase I & II and HDCV CAFE Standards Phase I share the similar structures, so I discuss them together in the first place. I define their structures as the ‘First Paradigm’. The defining feature of ‘First Paradigm’ is that there is ‘a maximum limit’ for each model according to its group and class. Figure 2 illustrates which CAFE standards are included in the ‘First Paradigm’ (those bubbles in the yellow circle). Table 5 summarizes different CAFE standards in the ‘First Paradigm’ in terms of some main aspects. Also, detailed information about the maximum limits for each set of CAFE standards in the ‘First Paradigm’ is provided in the Appendix

Table 1 to Table 3. To illustrate, I take Passenger Cars CAFE Standards Phase I as an example, but the same idea applies to the other CAFE standards in the 'First Paradigm'.

Firstly, all the models are divided into several groups according to some rules. For the passenger cars, models are divided into two groups. The first group is the baseline version. Models fall into this group if they do not qualify for the second group. The second group is the special structure, which includes models with auto transmission, models with 3 or more 3 rows of seats and/or SUVs.

Next, each group is further divided into several classes by the variable specified in the 'Classes by…' column in Table 5. In this example, each group is divided into 16 classes by curb weight. Now, we have 32 (= 2 * 16) classes.

Then, for each class, there is a maximum limit on fuel consumption level. The general pattern is that a model with a heavier body or a larger engine is subject to a less strict maximum limit. In this example, we have 32 different maximum limits since we have 32 passenger car classes. See Figure 3 for a graphical illustration.

After that, if a model does not meet its maximum limit, then it is not allowed to enter the market. As a result, the 'First Paradigm' is very rigid in this sense and doesn't have any flexibility. Thus, these standards regulate on the model level with maximum limits, instead of on the corporate average level[19]. Finally, some special rules might apply. In this example, vehicles weighing more than 3,500 kg, alcohol-only vehicles and natural-gas-only vehicles are not regulated by Passenger Cars CAFE Standards Phase I.

China chose to use a model level with maximum limits approach mostly for practical reasons. For instance, at the time of establishment of China Passenger Cars CAFE Standards Phase I & II, Chinese automotive market was highly fragmented, with over one hundred manufacturers. Many small and medium manufacturers only produced a few models in a niche segment (Wagner et al., 2009). A

[19] Strictly speaking, CAFE standards in the 'First Paradigm' cannot be called 'CAFE' since they don't regulate on the corporate average level. But, in this thesis I use the term 'CAFE' as a broader concept.

corporate-average approach would be unfair to those specializing in large vehicles, while hardly give any incentives to those small vehicle producers (Oliver et al., 2009). The same reasons apply to LDCVs and HDCVs as well.

The Structures and Features of 'Second Paradigm' in China CAFE Standards

The 'Second Paradigm' was firstly (and so far only) used in the China Passenger Cars CAFE Standards Phase III, which was released at the end of 2011. The biggest change is that in the 'Second Paradigm', 'targets' of fuel consumption levels are set, instead of the 'maximum limits'. The replacement of maximum limits with targets means that it is not mandatory to meet the target for a specific model. But, the mandatory compliance is now on the corporate level, as discussed below.

Like the 'First Paradigm', in the 'Second Paradigm' models are also divided into different groups and further into different classes. Each model will be subject to its own target according to which group and class it belongs to. For detailed information about targets, please see Appendix Table 4.

Figure 4 illustrates which CAFE standard is in the 'Second Paradigm'. Since only China Passenger Cars CAFE Standards Phase III uses 'Second Paradigm', I explain in its context. As we can see from Table 6, the passenger cars are first divided into two groups, the baseline version and the special structure. But, unlike Passenger Cars CAFE Standards Phase I & II, Phase III doesn't consider SUV as a type of special structures.

For each year, every manufacturer will calculate its Actual CAFC and Target CAFC. Actual CAFC and Target CAFC are defined in the following formulas:

$$\text{Actual CAFC} = \frac{\sum_1^N \text{FC}_\text{i} \times \text{S}_\text{i}}{\sum_1^N \text{S}_\text{i}}$$

$$\text{Target CAFC} = \frac{\sum_1^N \text{T}_\text{i} \times \text{S}_\text{i}}{\sum_1^N \text{S}_\text{i}}$$

where i is index for vehicle model, FC_i is the actual fuel consumption level for model i, T_i is the target fuel consumption level for model i and S_i is the actual sales for model i. For each manufacturer, the Actual CAFC is required not to exceed its own manufacturer-specific Target CAFC. Thus, the automotive industry is regulated on the corporate average level.

In the 'Second Paradigm', the concept of 'phase-in period' is also introduced. Although the Passenger Cars CAFE Standards Phase III is effective in mid-2012, the Target CAFC are adjusted 9 percent, 6 percent and 3 percent upwards in 2012, 2013 and 2014, compared with in 2015 and after.

The credits generated by over-compliance[20] can be used in the following three years. The inter-firm transfers of credits are not allowed, although similar ideas have been written into the draft version (but dropped in the final version).

China vs. US in CAFE Standards

US CAFE standards set the benchmarks for CAFE regulations around the world. For this reason, I compare China CAFE Standards with US CAFE Standards. Since US CAFE standards (Phase I & II) only regulate the passenger car and light truck segments, I choose China Passenger Cars CAFE Standards Phase I, II & III for comparison.

Table 7 summarizes the comparisons. The comparisons are either self-explanatory or explained as follows.

The punishment for non-compliance in China Passenger Cars CAFE Standards Phase III has not been announced yet, though some conjectures are discussed in the media.

Since credits are not allowed to be transferred across passenger car and light truck segments in US Phase I, I think the more accurate name of regulation approach for US Phase I would be 'Segment Average Level' instead of 'Corporate Average Level'. In the US Phase II, this limit is eliminated, which makes it truly deserve the name 'Corporate Average Level'.

[20] The portion of over-compliance generated by the phase-in period 'bonuses' is not counted as credits.

Generally speaking, US CAFE standards are much more mature than China CAFE standards, for 1) that US established its CAFE regulations much earlier than China, 2) that the credits transfer system is more advanced and developed, 3) that punishments are clearly stated, and 4) that US regulates on corporate average level earlier than China. However, China leads in at least one feature. China builds differences in maximum limits/targets for different models into its CAFE standards earlier than US.

Academic Research on China CAFE Standards

Academic research on China CAFE standards is very limited compared to that on US CAFE standards. Although some official studies supported by Chinese government have been done to collect data on China's fuel consumption levels, these studies or data are not available to the public. The lack of accurate and adequate data in China's public domain is a serious issue (Huo et al., 2012), which might partly explain the lack of Chinese studies.

In the limited body of research, most of the papers focus on the China Passenger Cars CAFE Standards Phase I & II. Sauer and Wellington (2004) are probably among the first group of academic researchers to analyze China's CAFE standards. (Note that China's first CAFE standards were released in September 2004 and their work was published in November 2004.) Their main purpose is to understand the strictness of Chinese standards and how difficult it is for American, European and Japanese automotive groups to comply with these standards. Due to the lack of data, they matched models produced by joint ventures in China with their original American, European and Japanese models, and derived fuel consumption levels of these models based on that. For example, for Chang'an-Ford[21] Focus, they used the data on fuel economy of the same model-year Ford Focus sold in US to derive its fuel consumption level.

Oliver et al. (2009) drew a clear picture of the policy-making backgrounds, including the motivations, major players and the policy-making process. Their work is quite helpful in understanding how Chinese

[21] Chang'an-Ford is a joint venture in China, established by Ford and the local auto maker Chang'an Automotive Group.

policy makers think. Their analysis of the impacts of the Passenger Cars CAFE Standards Phase I is quite comprehensive, which includes the overall compliance, impacts on the sales-weight average fuel consumption levels, technology progress, changes in vehicle characteristics, vehicle sales, fuel savings and reduction in GHG emissions.

Wagner et al. (2009) estimated the post-Phase I and post-Phase II fuel consumption levels for passenger car segment, by exploiting the first-ever publicly available official data on fuel consumption in China, which was released by China's National Development and Reform Commission (China NDRC) in October 2006 and July 2007. Also, they compared their results with all the precedent estimates by different studies.

Huo et al. (2011) examined the discrepancy (about 15.5 percent) between the real-world fuel consumption levels and the official laboratory test results. Due to a lack of accurate statistics on real-world fuel consumption data, theirs study is based on the voluntary reports by users on the internet. Their study also provided information about the testing cycle China is using, New European Driving Cycle or NEDC, to facilitate a better understanding of the discrepancy.

Huo et al. (2012)'s work is among the very few which discussed the overall picture of China's CAFE standards. They segmented Chinese vehicle market into light-duty vehicles, urban buses, inner-city buses, light-duty trucks, heavy-duty trucks, and explained how their segmentation is related to "GB/T 15089-2001" classifications (M_1, M_2, M_3, N_1, N_2, N_3, etc.). Their study actually cover more segments than those currently under regulations, such as city buses (which are exempt from HDCVs CAFE regulations according to a special rule). For each segment, they discussed the relevant CAFE standards and, more importantly, estimated the segment-wide fuel consumption level based on available public data, lab experiments they conducted and reasonable assumptions. Their work is of great importance since it provides an overall picture of China's CAFE standards and actual fuel consumption levels, as well as some guidelines for future policy making, in particular in the heavy-duty vehicle segment.

Ma et al. (2012) summarized the development of China Passenger Cars CAFE Standards Phase I, II and III. Then, they compared the actual fuel consumption levels with the CAFE maximum limits/targets in Phase I, II & III for models sold in Chinese automotive market in 2011. Based on their analysis, they concluded that for these models, it is hard for them to comply with the Phase III standards. Furthermore, they concluded that both Chinese domestic brands and imported brands have difficulty to comply with the Phase III standards.

Most of the studies on China CAFE standards are from an environmental engineering perspective, instead of from an economics point of view. The main empirical focus of these studies is to estimate the actual sales-weighted fuel consumption levels before, during and after the periods in which different phases of CAFE standards are effective, or simply compare the actual and target fuel consumption levels model by model.

There are some major drawbacks of these studies. First of all, the availability of data is a serious issue. Many assumptions or compromises have to be made for data matching and calculations. For example, the sales data or fuel consumption data they use are rarely at the model level, needless to say at the trim level. Next, for the methodology, none of them have utilized any regressions to analyze data in the empirical studies. Moreover, these studies are silent about the changes in vehicle characteristics (weight, engine power, etc.). As a result, the welfare losses of implementing CAFE standards have not been analyzed in these studies.

Chapter 4 Data Used in the Empirical Studies

Some Unique Features about Chinese Automotive Market

Before I discuss the data, it is worth mentioning several unique features of Chinese automotive market. As we will see later in the empirical studies, these features are reflected in the data I use in the empirical studies and have impacts on the empirical results. Thus, it is important to understand them.

The first feature is the differences in model definitions. There are some differences between China and US. Firstly, hybrid/electric and non-hybrid/electric vehicles are defined as different models in China, while they are considered different trims of the same model in US. Secondly, not like in US, different body styles (such as sedan, coupe, hatchback and convertible) are considered as different models in China. For example, SAIC-GM-Chevrolet Cruze Sedan and SAIC-GM-Chevrolet Cruze Hatchback are different models.

The second feature is the existence of joint ventures, which creates a unique characteristic in Chinese automotive industry. The foreign automobile makers are required to establish joint ventures (JVs) with one or more local auto makers in order to produce and sell their models legally in China. In the meanwhile, they are also allowed to directly import their models to China under their own operations. It is possible that models with the same name are both produced locally by JV and imported by its original foreign auto maker. The JV models are sold under the JV brands, while the directly imported models are sold under the imported brands. To illustrate, let us look at an example. FAW-Audi Q3 is a model produced by the FAW-Audi (a joint venture) and is sold under the JV brand ‘FAW-Audi’, while Audi Q3 Import is a model directly imported by VW and is sold under the imported brand ‘Audi’. The word ‘Import’ is added to the model name to reflect the distinction between a JV model and an imported model.

The third feature is the significant sales lag-effect in Chinese automotive market. Probably due to the huge income discrepancy among different areas in China, a model of previous years, which might be considered as outdated in coastal cities in Eastern China, can still sell in inner land cities in Western China. As a result, it is possible that, for example, a 2012 Audi Q3 is still sold in the new vehicle market in 2014.

Trim-Level Vehicle Characteristics Dataset

The trim-level vehicle characteristics dataset is acquired from Xcar (http://www.xcar.com.cn/), a professional online media specializing in automobiles. The dataset covers all passenger car models sold in China, and it also includes some non-passenger car segments, such as light bus, mini truck, pickup and minivan. The dataset covers the period from 2009 to 2013.

Data is at trim-level, and thus each observation represents a trim of a model in a specific year. A typical observation would be like, for example, 'Cadillac XTS 2013 36S Platinum'. In this example, '2013', together with '36S Platinum', identifies a trim of the model 'Cadillac XTS'. '2003' is the model year, and '36S' means 3.6 L engine displacement (36) and gasoline direct injection engine (S). Typically, different engines, drive wheel types, fuel types and transmission types are defined as different trims.

The dataset includes model name, trim name, brand, model year, sales-start year, segment, fuel consumption (L/100 km), engine power (kW), weight (kg), torque (N*m), turbocharger[22], MSRP (RMB), number of speeds, transmission type, drive wheel type, fuel type (gas or diesel), fuel injection type and hybrid (hybrid vs. non-hybrid) as variables.

To analyze the heterogeneities across different countries and manufacturers, based on the 'Brand' variable I create two variables, 'Country' and 'Manufacturer'. Firstly, the 'Manufacturer' variable is created based on the 'Brand' variable. Examples are that SAIC-GM (a joint-venture manufacturer) is associated with SAIC-GM-Chevrolet, SAIC-GM-Buick and SAIC-GM-Cadillac, that SAIC (a Chinese manufacturer) is associated with Roewe and MG, and that GM (a US manufacturer) is associated with Buick, Chevrolet,

[22] This variable distinguishes between different types of air intake, including naturally aspirated engine, turbocharger, supercharger, twincharger and others.

Cadillac, Hummer, GMC and Opel. Secondly, the 'Country' variable is also created based on the 'Brand' variable to distinguish between imported brands, joint-venture brands and Chinese brands. Vehicles under Chinese brands are those produced by local Chinese manufacturers. Vehicles under imported brands are those directly imported to China, and are further distinguished between different countries of origins. Vehicles under joint-venture brands are those produced by joint ventures in China, and are also further distinguished between different countries of origins. For example, 'FAW-Hongqi' is classified as a Chinese brand, 'FAW-VW' is classified as a joint-venture brand with Germany origin, and 'VW' is classified as an imported brand with Germany origin. For a complete matching between brands, countries and manufacturers, please see Appendix Table 5.

Trim-Level Vehicle Monthly Sales Dataset

Vehicle monthly sales dataset is generously shared by Professor Shanjun Li, one of the advisors of this thesis. Data is also at the trim level. Due to lack of information, trims in this dataset cannot be exactly mapped to trims in Xcar vehicle characteristics dataset. But, the model name is a bridge to partially link these two dataset together.

Monthly sales volumes are available for each trim from January 2008 to December 2012. However, information on model year is not included in this dataset. But, from the monthly sales volumes, I can derive the sales-start year, defined as the year of the first month in which sales is not zero[23]. For this reason, throughout the empirical study, the time dimension I use is sales-start year of the model, not the model year.

After creating the 'sales-start year' variable, then I create three variables for the vehicle monthly sales dataset, that are, 'Manufacturer', 'Segment' and 'Approximate Fuel Consumption'. The former two variables are created to associate each trim in the vehicle monthly sales dataset to the 'Manufacturer' variable and the 'Segment' variable in Xcar vehicle characteristics dataset. The 'Approximate Fuel

[23] For those models with non-zero sales in January 2008, the assumption is that their sales-start year is 2008.

Consumption' variable is calculated in the way that the 'Fuel Consumption' variable in Xcar dataset is averaged by model by sales-start year, and then associated with each trim in the vehicle monthly sales dataset[24]. Thus, trims within a sales-start year and a model have the same 'approximate fuel consumption' level in the vehicle monthly sales dataset.

The dataset also includes model name, trim name, brand, weight (kg), engine power (kW) and MSRP (RMB) as variables.

[24] The only exception is for the 2008 observations. Since Xcar dataset only covers 2009 to 2013, the 2008 fuel consumption data is not available and is extrapolated from 2009-2013 fuel consumption data for the same model.

Chapter 5 Estimation of the Technology Trade-offs and the Technology Progress for China's Passenger Car Segment

What are the Technology Trade-offs and the Technology Progress and why do We Need Them?

Following Knittel (2011) and Klier and Linn (2013), I define the technology trade-offs as the trade-offs between fuel economy, weight, torque and engine power. It is also known as the 'technology frontier' or the 'production possibilities frontier (PPF)'. The technology progress is defined as how the technology frontier shifts over years, and is also known as the 'fuel economy efficiency'.

Figure 5[25] illustrates these two concepts. The vertical axis is fuel consumption (measured in L/100 kilometers), and the two horizontal axes are weight and engine power. More weight or more engine power results in higher fuel consumption (i.e. lower fuel economy). Given a technology progress level, the manufacturer can only move on the technology frontier and simultaneously choose fuel consumption, weight and engine power. If the technology progress level is higher, then the entire technology frontier shifts downwards (in the direction at which the yellow arrows point).

Knittel (2011), in his groundbreaking paper, for the first time in the CAFE standards literature, took into consideration the technology trade-offs and the technology progress. Klier and Linn (2013) also pointed out that the failure to account for the changes in weight and engine power (due to the technology trade-offs) biases the welfare losses towards zero.

I would like to use some words and facts to intuitively explain why it is important to include the technology trade-offs and the technology progress for any studies on the welfare effects of CAFE standards.

US experiences provide a good example for illustration. Remember from the previous section, US CAFE standards for passenger cars remained almost flat after MY 1985. As a result, average fuel economy

[25] The idea is from Klier and Linn (2013). However, their paper only provides a two-dimension illustration of the trade-offs between fuel economy and horsepower, keeping weight fixed.

levels of new cars sold in US increased by less than 6.5 percent, while average horsepower and average weight increased by 80 percent and 12 percent, respectively (Knittel, 2011). The light truck segment experienced an even larger increase in average horsepower and average weight (Knittel, 2011). For a graphical illustration, see Figure 1 of Klier and Linn (2013), in which they plotted sales-weighted average fuel economy, weight and horsepower for cars sold by US manufacturers from 1975 to 2008. If only fuel economy is considered in the policy evaluations, then it is natural to conclude that US CAFE standards failed to contribute to social welfares after MY 1985.

However, the fuel economy is not free. Except for the costs from the manufacturers' side (R&D, etc.) to comply with CAFE standards, there are also costs on the consumers' side. Consumers are forced to purchase vehicles with less powerful engines and less weight. If only the benefits from improvements in fuel economy are counted, it would be a biased cost-benefits analysis. Thus, to better understand the welfare benefits and losses of CAFE standards, we need to estimate the trade-offs between fuel economy, weight, torque and engine power, and to figure out how the underlying fuel economy efficiency progresses over time. Also, when analyzing how the fleet's fuel economy would comply with potential future CAFE standards, we will also need the estimated technology trade-offs and the estimated technology progress in our back pockets.

Furthermore, the estimated technology progress also allows us to compare fuel economy efficiencies across different countries and manufacturers. The basis for these comparisons is that the trade-offs between fuel economy, weight, torque and engine power should be controlled. Otherwise, it makes little sense when I compare a firm which specializes in SUVs and pickups with a mini-car auto maker purely in terms of fuel consumption.

Empirical Specifications

In the baseline model, the technology progress is modeled as the year fixed effects. Due to this model setting, the technology progress is not assumed to be linear in years. The magnitude of year fixed effects is interpreted as the reduction in fuel consumption in percentage relative to the base year. In this model, the technology trade-offs is assumed to be constant (i.e. the technology progress is neutral with respect to weight, torque and engine power, and the coefficients of weight, torque and engine power don't change) throughout the sample period.

Following Knittel (2011), I choose both Cobb-Douglas function and Translog function as the functional forms. In both specifications, the left-hand side variable is log fuel consumption. In the Cobb-Douglas functional form, the right-hand side variables include log weight, log engine power and log torque. In the Translog functional form, the right-hand side variables include log weight, log engine power, log torque, as well as the square terms and the cross-product terms of these variables. Other vehicle characteristics variables are controlled as fixed effects.

In the baseline model, the trade-offs is modeled as:

$$\ln \mathrm{FC}_{it} = \tau_t + \beta_1 \ln \mathrm{Weight}_{it} + \beta_2 \ln \mathrm{EnginePower}_{it} + \beta_3 \ln \mathrm{Torque}_{it} + \sum_j \beta_j X_{ijt} + \varepsilon_{it}$$

and,

$$\ln \mathrm{FC}_{it} = \tau_t + \beta_1 \ln \mathrm{Weight}_{it} + \beta_2 \ln \mathrm{EnginePower}_{it} + \beta_3 \ln \mathrm{Torque}_{it} + \gamma_1 (\ln \mathrm{Weight}_{it})^2 + \gamma_2 (\ln \mathrm{EnginePower}_{it})^2 + \gamma_3 (\ln \mathrm{Torque}_{it})^2 + \delta_1 \ln \mathrm{Weight}_{it} \ln \mathrm{EngingPower}_{it} + \delta_2 \ln \mathrm{Weight}_{it} \ln \mathrm{Torque}_{it} + \delta_3 \ln \mathrm{EnginePower}_{it} \ln \mathrm{Torque}_{it} + \sum_j \beta_j X_{ijt} + \varepsilon_{it}$$

where log fuel consumption is the left-hand side variable, log weight, log engine power, log torque, their square terms and their corss-product terms are included as right-hand side variables, τ_t represents the year fixed effects, X_{ijt} represents other vehicle characteristics fixed effects and ε_{it} represents the error terms. X_{ijt} may or may not include turbocharger, fuel type, fuel injection type, hybrid, number of speeds, transmission type, drive wheel type, brand and segment, depending on different specifications.

Another implicit assumption in the baseline model is that the technology progress is the same for each vehicle model. According to Klier and Linn (2013), this assumption is not realistic. Manufacturers adopt new technologies to improve fuel economy efficiency at different paces. Furthermore, each model may have its own schedule of design cycle.

The best solution is to find a way to incorporate into the empirical models the model-level heterogeneities in the technology progress, such as the approach adopted by Klier and Linn (2013). However, the unbalanced feature of my dataset does not allow too many fixed effects to be identified. As a second-best solution, I decompose the technology progress into the segment-year interaction fixed effects, as[26]:

$$\ln \mathrm{FC}_{it} = \tau_{st} + \beta_1 \ln \mathrm{Weight}_{it} + \beta_2 \ln \mathrm{EnginePower}_{it} + \sum_j \beta_j X_{ijt} + \varepsilon_{it}$$

and,

$$\ln \mathrm{FC}_{it} = \tau_{st} + \beta_1 \ln \mathrm{Weight}_{it} + \beta_2 \ln \mathrm{EnginePower}_{it} + \gamma_1 (\ln \mathrm{Weight}_{it})^2 + \gamma_2 (\ln \mathrm{EnginePower}_{it})^2 + \delta_1 \ln \mathrm{Weight}_{it} \ln \mathrm{EngingPower}_{it} + \sum_j \beta_j X_{ijt} + \varepsilon_{it}$$

where log fuel consumption is the left-hand side variable, log weight, log engine power, their square terms and their corss-product terms are included as right-hand side variables, τ_{st} (in replace of τ_t) represents the segment-year interaction fixed effects, X_{ijt} represents other vehicle characteristics fixed effects and ε_{it} represents the error terms. X_{ijt} may or may not include turbocharger, fuel type, fuel injection type, hybrid, number of speeds, transmission type, drive wheel type and brand, depending on different specifications. Note that there are no segment dummies in X_{ijt} in these two specifications.

Baseline Empirical Results

The estimates of the baseline models are shown in Table 8 to Table 11. Table 8 and Table 9 show estimation results in the Cobb-Douglas specification, and Table 10 and Table 11 show estimation results in the Translog specification. Regressions in Table 8 and Table 10 cover all the observations in the dataset, while those in Table 9 and Table 11 only cover passenger cars observations and exclude the 'Torque'

[26] Note that in the Translog function, the variable 'Torque' is dropped.

variable in the right-hand side. Following Klier and Linn (2013), I exclude the ‘Torque’ variable in the passenger cars regressions because engine power and torque are highly correlated with each other, and for passenger cars, fuel consumption is more related to engine power. In the rest of discussions, I will focus on Table 8 since passenger car segment is the focus of this empirical study and Cobb-Douglas functional form is easy to interpret. However, similar interpretations apply to Table 9, Table 10 and Table 11 as well.

Since all the variables (except the fixed effects) are in log, the estimates of the coefficients for log engine power, log weight and log torque are interpreted as elasticities. For example, in Table 8, the estimated elasticity for engine power is from 0.202 to 0.271. It means that if engine power increases by 1 percent, fuel consumption will increase by from 0.202 percent to 0.271 percent.

The regressions include different sets of fixed effects for different specifications, such as sales start year, turbocharger, fuel type, fuel injection type, hybrid, number of speeds, transmission type, drive wheel type, brand and segment. Among these fixed effects, only estimates of sales start year fixed effects are reported since these represent the technology progress in the baseline model. From Table 8, we know that the technology progress over the period from 2009 to 2013 is estimated to from 9.11 percent to 12.1 percent. The interpretation is that the fuel consumption level of a model (beginning to sell) in 2013 is from 9.11 percent to 12.1 percent less than a model (beginning to sell) in 2009, since 2009 is the baseline year. In other words, the technology progress is estimated to be from 9.11 percent to 12.1 percent over the period from 2009 to 2013.

Furthermore, I distinguish between the ‘residual’ technology progress and the ‘total’ technology progress. All the fixed effects (except brand and segment) represent technologies related to fuel economy improvements. Manufacturers achieve the technology progress either by improving these fuel-economy-related fixed (such as turbocharger, transmission type, etc.) or by utilizing those technologies which cannot be easily and explicitly modeled (mainly advanced engine technologies, and here I call them ‘residual’ technologies). If these fuel-economy-related fixed effects are included in the regressions, then the estimated technology progress represented by sale start year fixed effects would be the 'residual' technology progress excluding these fuel-economy-related fixed effects. As an illustration, the column (1) in Table 8 reports the estimated 'residual' technology progress to be 9.31 percent over the period from 2009 to2013.

On the other hand, if these fuel-economy-related fixed effects are not included in the regressions, the estimated technology progress would be the 'total' technology progress. As we see from the column (3) of Table 8, the estimated 'total' technology progress over the period from 2009 to2013 is 11.9 percent, larger than the estimated 'residual' technology (9.31 percent) in the column (1) of Table 8.

The reason for the difference is that the fuel-economy-related fixed effects are correlated with sales start year since more fuel-economy-related technologies (such as turbocharger, fuel-saving transmission technology, etc.) are adopted in recent years. Thus, the estimates of coefficients for sales start years incorporate these fuel-economy-related fixed effects and are interpreted as the 'total' technology progress. Though the incorporation is not perfect since these fuel-economy-related fixed effects might also correlate to weight and engine power, it could still provide some insights.

Lastly, one point needs to be mentioned. The technology progress estimated here is totally from the production side. No matter how many units each trim sell, it will be represented as one observation in the regression. This point applies to all the regression results in this chapter. In the next chapter, I will use sales volumes as weights to average these estimated technology progress, and the number would be different from estimates reported in this chapter. The reason is that the sales-weighted averages reflect consumers' choices.

By-Segment Baseline Empirical Results

In this section, the Xcar dataset is divided into sub-samples by segment group and separate regressions are run for different segment groups. Only Cobb-Douglas specification is estimated in this section and only passenger cars are included in the sub-samples.

Table 12 and Table 13 report the estimation results of by-segment baseline model regressions. Table 12 includes all the fixed effects while Table 13 only includes brand and sales start year fixed effects. Thus, we could compare the estimated ‘residual’ technology progress (in Table 12) with the estimated ‘total’ technology progress (in Table 13). In Table 12 and Table 13, each column reports the estimation results for a segment group. For example, column (1) in Table 12 only includes ‘Compact’, ‘Small’ and ‘Mini’ segments in the regression.

By comparing the results within Table 12 and 13 but across segments, we can see that heterogeneities do exist across different segments. In Table 12, estimates of coefficients for log engine power and log weight vary from 0.116 to 0.313 and from 0.204 to 0.525, respectively. In Table 13, the variations are also significant. These results suggest that the technology trade-offs between fuel economy, weight and engine power are not constant across segments.

From the comparisons across segments, we could see that different segments also vary in the technology progress (from 4.21 percent to 10.5 percent in the sample period as reported in Table 12, for instance). This provides empirical evidences to support estimation of a separate technology progress curve for each segment, as done in the next section.

By comparing results within the same segment but across Table 12 and 13, we could also see that for some segments the difference between the estimated ‘total’ technology progress and the estimated ‘residual’ technology progress is also significant. For example, column (3) in Table 12 reports the estimated ‘residual’ technology progress for ‘Medium’ segment to be 7.65 percent over the sample period, while the same column in Table 13 reports the estimated ‘total’ technology progress for the same segment to be 14.7 percent for the same period.

Allow for Segment Heterogeneity in the Technology Progress

As explained above, assuming the technology progress across different models to be the same is not realistic. To allow segment heterogeneities in the technology progress, I decompose the sales start year fixed effects into the segment-sales start year interaction fixed effects and estimate a separate technology progress curve for each segment. The empirical model is explained in details in the previous section.

Both Cobb-Douglas and Translog functional forms are estimated and different sets of fixed effects are controlled in different specifications. However, only passenger car segment is included in the regressions.

The results are reported in Table 14 (for Cobb-Douglas functional form) and Table 15 (for Translog functional form). Furthermore, to provide a better graphical representation, the estimated technology progress curves in column (1) and column (2) of Table 14 and 15 are plotted in Figure 6 to Figure 9. Note that the column (1) specifications include all the fixed effects, and the column (2) specifications only include brand dummies and segment-sales start year interaction fixed effects. Thus, results in the column (1) should be interpreted as the segment-specific ‘residual’ technology progress, while those in column (2) as the segment-specific ‘total’ technology progress.

Let me take Figure 6 as an example to explain how to understand these figures. In Figure 6, the estimated segment-sales start year interaction fixed effects are plotted as 9 curves (one curve for each segment). The baseline is ‘Sports 2013’, as indicated in the dotted-border rectangle. It means that the ‘residual’ technology progress of ‘Sports 2013’ is assumed to 100 percent, and all other estimates should be interpreted relative to ‘Sports 2013’.

To interpret the differences between baseline model and segment heterogeneity model, I take Table 8 and Table 14 as examples to explain. From the estimates of coefficients for log engine power and log weight, we could see that they do not vary much across Table 8 and Table 14. It suggests the robustness of estimates of these coefficients in the baseline model. However, the estimates of technology progress are quite different across the baseline model and the segment heterogeneity model, and across different segments in the segment heterogeneity model. For example, from Figure 6, in which the estimated 'residual' technology progress curve for each segment is plotted, we could see that there do exist some heterogeneities in the technology progress across segments. The 'Luxury' segment has much faster 'residual' technology progress, while the 'Sports' segment is stagnant. This pattern also appears in Figure 7 to Figure 9. Thus, the conclusion is that the 'Luxury' segment has a faster technology progress while the 'Sports' segment lags behind in technology progress.

Country Effects and Manufacturer Effects

As mentioned in the previous chapter, China CAFE regulations aim to push both domestic manufacturers and foreign automotive groups to improve fuel economy efficiency. From a CARATC report (Gao and Jin, 2011), we know that more than 400 models were eliminated after China Passenger Cars Phase I was effective. However, after then, how firms have improved the fuel economy efficiency of other surviving models has not been examined yet. Furthermore, given the low technology levels in local Chinese auto makers, how Chinese brands catch up with joint-venture brands and imported brands in fuel economy efficiency also remains to be answered. Fortunately, the baseline model for the estimations of the technology trade-offs and the technology progress could provide us a chance to answer that question.

To do that, I modify the Cobb-Douglas specification in the baseline model, as:

$$\ln \mathrm{FC}_{\mathrm{it}} = \tau_{\mathrm{t}} + \beta_1 \ln \mathrm{Weight}_{\mathrm{it}} + \beta_2 \ln \mathrm{EnginePower}_{\mathrm{it}} + \sum_{\mathrm{j}} \beta_{\mathrm{j}} \mathrm{X}_{\mathrm{ijt}} + \varepsilon_{\mathrm{it}}$$

and,

$$\ln \mathrm{FC}_{\mathrm{it}} = \mathrm{t} * \mathrm{D}_{country} + \beta_1 \ln \mathrm{Weight}_{\mathrm{it}} + \beta_2 \ln \mathrm{EnginePower}_{\mathrm{it}} + \sum_{\mathrm{j}} \beta_{\mathrm{j}} \mathrm{X}_{\mathrm{ijt}} + \varepsilon_{\mathrm{it}}$$

where log fuel consumption is the left-hand side variable, log weight and log engine power are included as right-hand side variables, X_{ijt} represents other vehicle characteristics fixed effects and ε_{it} represents the error terms.

In the first equation, τ_t represents the year fixed effects. The first equation looks the same as the Cobb-Douglas specification in the baseline model, however there is one difference. In the first equation, X_{ijt} does not include brand dummies but instead include country dummies or manufacturer dummies[27]. Country dummies or manufacturer dummies are included in the first equation to estimate the country-specific levels of technology progress over the sample period.

The second equation is similar to the first one, but differs in the following aspects. In the second equation, $D_{country}$ are country dummies and t represents time index ('1' for Year 2009, '2' for Year 2010, '5' for Year 2013, etc.). The term product term $t * D_{country}$ is included in the second equation to estimate the country-specific paces of technology progress over the sample period. An implicit assumption here is that each country has a constant pace of technology progress over the sample period (i.e. a linear trend in technology progress over time). X_{ijt} in the second equation does not include brand dummies, country dummies or manufacturer dummies.

Only Cobb-Douglas functional form is estimated and only passenger cars are included in the sample. Also, note that country effects are modeled in both equations, while manufacturer effects are only modeled in the first equation. In some regressions, country dummies are further grouped into China, Japan, Korea, Europe and JV.

The estimation results of country effects are reported in Table 16 to Table 19 and Figure 10 to Figure 13, while those of manufacturer effects are reported in Table 20, Figure 14 and Figure 15.

[27] See Chapter 4 for the descriptions of the Xcar dataset.

Table 16 and Table 17 report the estimation results of country effects for the first equation. The difference is that Table 16 uses ungrouped country dummies and Table 17 uses grouped country dummies. The difference between column (1) and column (2) in both tables is that column (1) includes the fuel-economy-related fixed effects and column (2) does not. Thus, the estimated country effects in column (1) are the 'residual' country-specific levels of technology progress while those in column (2) are the 'total' country-specific levels of technology progress. In both tables, China is the baseline country. Thus, the estimates of country effects are interpreted as the difference in the levels of technology progress versus China. For example, from column (1) of Table 16, we see that the estimated coefficient for 'JVGermany_CE' is -1.68 percent. That means relative to Chinese local brands, joint-venture brands with Germany origin, on average, are 1.68 percent more advanced in the level of 'residual' technology progress. As graphical illustrations, Figure 10 reports estimates of country effects (of selected countries) for Table 16, while Figure 11 reports estimates of country effects (of selected countries) for Table 17.

Table 18 and Table 19 report the estimation results of country effects for the second equation. Similarly, the difference is that Table 18 uses ungrouped country dummies and Table 19 uses grouped country dummies. Similar difference exists between column (1) and column (2). In Table 18 and Table 19, the estimates of country effects are interpreted as the country-specific average yearly paces of technology progress over the sample period. For example, from column (1) of Table 18, we see that the estimated coefficient for 'JVGermany_CE_t' is -2.48 percent. That means joint-venture brands with Germany origin, on average, have progressed in fuel economy technology over sample period by 2.48 percent yearly. As graphical illustrations, Figure 11 reports estimates of country effects (of selected countries) for Table 18, while Figure 12 reports estimates of country effects (of selected countries) for Table 19.

From these country effect estimation results, I make the following conclusions. The first conclusion is about the level of 'total' technology progress. Imported brands are most advanced. Imported brands with Europe origin (mainly contributed by those with Germany origin) lead in the first place with 7.06 percent higher in the level of 'total' technology progress relative to Chinese local brands, followed by imported brands with Japan origin (5.37 percent higher) and with Korea origin (3.35 percent higher). JV brands (2.52 percent higher) come after imported brands, mainly contributed by JV brands with Germany origin and with Korea origin. Chinese local brands lag behind imported brands and JV brands in the level of 'total' technology progress.

Secondly, differences exist between levels of 'total' technology progress and levels of 'residual' technology progress. From Figure 10 and Figure 11, we could easily see that the rankings would be somewhat different for the level of 'residual' technology progress. In terms of the level of 'residual' technology progress, Chinese local brands still rank below imported brands (by from 1.15 percent to 4.59 percent) and JV brands (by 2.31 percent). Imported brands with US origin rise to the first place in terms of the level of 'residual' technology progress though they rank even after Chinese local brands in terms of the level of 'total' technology progress.

Thirdly, in terms of the pace of technology progress (both 'total' and 'residual'), Chinese local brands rank in the penultimate place, behind some imported brands and JV brands. Thus, the gap between Chinese local brands and imported/JV brands are getting larger and larger. This is possibly because China CAFE standards are designed to be bottom heavy[28] and thus Chinese local brands are faced with less pressure from CAFE standards. Whether or not this type of 'protection' for Chinese local brands is good remains a question. However, it provides a warning for the policy maker that Chinese local brands lagged behind in terms of the level of technology progress (both 'residual' and 'total') and failed to catch up with imported/JV brands over the sample period.

Manufacturer Effect Estimation Results are reported in Table 20, Figure 14 and Figure 15. Similarly, Column (1) and Column (2) in Table 20 distinguish between the level of 'residual' technology progress and level of 'total' technology progress. Estimates of selected manufacturer effects are illustrated in Figure 14 (column (1)) and Figure 15 (column (2)). Similar conclusions could be drawn as those in

[28] As discussed in Chapter 3.

country effects. From estimates of manufacturer effects, we could clearly see which firms actually drive the level of technology progress behind country effects.

Chapter 6 Where is China Located on the Technology Frontier and where will it Head for?

What Actually Happened in the Past?

Over the period from 2009 to 2012, China's overall fuel consumption levels kept decreasing. Figure 16 shows the sales-weighted average fuel consumption, engine power and weight over the period from 2009 to 2012. The three time series are normalized to show the percentage change relative to 2009. From Figure 16, we could clearly see that the average fuel consumption has decreased by about 3.5 percent. In the same period, the weight and engine power increased by 2.82 percent and 8.69 percent, respectively.

The period from 2009 to 2012 is almost between Phase II and Phase III of China Passenger Cars CAFE regulations. Recall from the previous section that the China Passenger Cars CAFE Standards Phase II was effective in January 2008 (for new models) and January 2009 (for old models) and that it was released in September 2004. Thus, manufacturers have plenty of time to prepare for Phase II regulations. As a result, the impacts of the Phase II standards could be hard to detect in the data I use. On the other hand, China Passenger Cars CAFE Standards Phase III was not released until December 2011. Thus, the impacts of the Phase III standards are also not reflected in the data.

For these reasons, the purpose of my study is not to analyze the policy impacts. Instead, I focus on applying the estimates of the technology trade-offs and the technology progress to unveil the underlying stories of China's past improvements in fuel economy and to analyze the feasibility for the future improvements in fuel economy.

What could have Happened? -- The Underlying Stories

Knowing what could have happened is more important than knowing what actually happened, since the underlying stories determine the direction where we are heading now and in the future. Combining the vehicle sales dataset with the estimated technology trade-offs and the estimated technology progress, I would address this question shortly.

The analysis done in this section follows Klier and Linn (2013). The results are reported in Figure 17 to Figure 20. I use four sets of estimates to calculate the technology progress curve and conduct the what-if analysis which assumes engine power and weight are kept constant at their 2009 level.

For Figure 17 and Figure 18, I use estimates in column (1) and (3) of Table 8, respectively. These are the baseline model estimations using Cobb-Douglas functional form for passenger car segments. The column (1) includes all the fuel-economy-related fixed effects, thus the estimated technology progress curve is the 'residual' technology progress. The column (3) only includes brand dummies and segment dummies, thus the estimated technology progress is the 'total' technology progress.

For Figure 19 and Figure 20, I use estimates in column (1) and (2) of Table 14, respectively. These are also Cobb-Douglas specifications but allow for a separate technology progress curves for each segment. Similarly, estimates in column (1) are considered as the 'residual' technology progress, while those in column (2) as the 'total' technology progress.

The 'Fuel Consumption' curves in Figure 17 to Figure 20 are the same as it is in Figure 16, representing the sales-weighted average economy-wide fuel consumption levels. The what-if analysis results are reported as 'Keep Engine Power Constant' curves and 'Keep Weight Constant' curves. Since the estimated coefficients for log engine power and log weight don't vary much in different specifications, the 'Keep Constant' curves hardly change in Figure 17 to Figure 20. Thus, the interpretations for these curves are the same. The conclusion is that the actual fuel consumption level could have been even lower if engine power and weight stayed at their 2009 level.

The solid black curves represent the realized sales-weighted average technology progress over time, estimated based on 1) either baseline model estimations or segment heterogeneity model estimations and 2) either the 'total' technology progress or the 'residual' technology progress. According to the estimates in Figure 17 to Figure 20, the realized ‘residual’ technology progress over the four-year period (2009-2012) is about 3.99 percent to5.86 percent, and the realized ‘total’ technology progress over the four-year period (2009-2012) is about 5.50 percent to 6.04 percent. It is reasonable that the estimated ‘residual’ technology progress is less than the estimated ‘total’ technology progress, since the latter includes the positive effects of fuel-economy-related fixed effects on fuel economy.

Also, note that in the Figure 17 and Figure 18, the dotted black curves represent the estimates of the technology progress directly from column (1) and (3) in Table 8. These estimates are not averaged by weights of sales volumes, thus they purely reflect the technology progress from the production side. There are two reasons that the dotted and solid black curves do not overlap. Firstly, the dotted curves represent the average technology progress in which each trim has the same weight, while the solid curves are the sales-weighted average technology progress. Secondly, the dotted curves represent the technology progress for all models which first become available for sales in that year, while the solid curves represent all vehicles actually sold in that year. A unique feature in Chinese automotive market is that a new model typically continues to sell for many years, which is known as the sales lag-effect. Thus, the solid curves actually represent the technology progress levels of models from both current year and previous years.

What will Happen in the Future -- The Compliance Matrices

In 2012, Chinese government raised an ambitious plan in a formal announcement to achieve the overall fuel consumption level for passenger car segment of 6.9L/100 km and 5.0 L/100 km, in 2015 and 2020, respectively (The State Council of China, 2012). Based on the estimated technology trade-offs and the estimated technology progress, I can provide a rough estimate of the feasibility of these objectives for 2015 and 2020.

Table 21 and Table 22 report the compliance matrices for 2015 and 2020, respectively. The base year is 2012, in which sales-weighted average fuel consumption, engine power and weight are 7.678 L/100 km, 97.578 kW and 1716.465 kg respectively. The coefficients for log engine power and log weight in the technology trade-offs equation used in the compliance analysis are the arithmetic average of those used in Figure 17 to Figure 20.

In the sensitivity tables, the rows are different scenarios for the yearly technology progress in percentage. We could compare the different scenarios of yearly technology progress with the estimated the ‘total’ technology progress. The reason that we compare it with the ‘total’ technology progress instead of the ‘residual’ technology progress is that for improvement in fuel economy in the real world, manufacturers could utilize every technology they have. For readers’ information, the actual yearly technology progress is roughly 2.0 percent for the ‘total’ technology progress. Thus, I highlight ‘2.00 percent yearly technology progress’ scenario in the 2015 table and the ‘2.05 percent yearly technology progress’ scenario in the 2020 table. Readers could think the highlighted scenario as the most realistic scenario.

The columns are different scenarios for the yearly percentage change in weight and engine power. From Figure 16, we know that the ratio of the percentage change in engine power to the percentage change in weight is roughly 3 to 1 over the period from 2009 to 2012. Thus, the same ratio is assumed in the scenarios in the sensitivity tables. For every 1 percent of change in weight, engine power is assumed to change by 3 percent.

Solid black lines are used to separate those situations which meet the objectives and those which do not. Also colors are used to reflect the magnitudes of the fuel consumption levels. More green colors represent lower fuel consumption (i.e. better fuel economy).

Read from the matrices, I make the following conclusions. Firstly, the objectives are very aggressive and difficult for firms to meet, especially the 2020 objective. Only a few very optimistic scenarios could achieve these objectives. For example, even in a somewhat optimistic scenario with yearly technology progress of 3 percent, Chinese automotive industry still needs to at least downsize yearly in weight and engine power of 3 percent and 9 percent, respectively, to meet the objective in 2015 of 6.9 L/100 km.

Secondly, to achieve the objectives, firms have two options. The first option is to significantly speed up the technology progress by roughly doubling it. In this case, firms could keep the weight and engine power constant at the 2012 levels and still achieve the objectives. The second option is to moderately speed up the technology progress and seriously downsize in weight (by at least 3 percent yearly) and in engine power (by at least 9 percent yearly).

Chapter 7 Welfare Analysis for Improving Fuel Economy in China

Empirical Model for Willingness-to-Pay Estimation

In order to calculate the welfare losses of improving fuel economy, the first thing to do is to estimate the willingness-to-pay (WTP) for weight and engine power. In this section, I specify the empirical model for the WTP estimation.

In the automotive market, segment is clearly defined and commonly known among consumers and manufacturers. Manufacturers carefully design their model portfolios to compete with competitors segment by segment. Consumers first choose whether or not to buy a new vehicle, next choose a segment, and finally purchase a model in that segment (Klier and Linn, 2012). Thus, a nested logit model of demand is a natural choice for modeling consumers' choices in purchasing vehicles.

One of the advantages of nested logit model of demand is that there exists a closed form of demand function. Following Berry (1994), I specify the demand function as follows:

$$\ln s_{jt} - \ln s_{0t} = \alpha \ln \mathrm{Price}_{jt} + \beta X_{jt} + \sigma \ln s_{j|s} + \xi_{jt}$$

where the subscript j is the product j, which is a trim in my dataset, and the subscript t is the market t, defined as one month sales in China in my dataset. The dataset I used covers monthly sales from January 2008 to December 2012, thus in total I have 60 markets (t = 1, 2…60). s_{jt} is the market share of product j in market t, while s_{0t} is the market share of outside goods in market t. The outside goods is defined as not purchasing a new vehicle. Price_{jt} is the manufacturer's suggested retail price (MSRP), and X_{jt} is a series of vehicle characteristics, which include fuel consumption, weight, engine power, old model[29] and manufacturer dummies. $s_{j|s}$ is the intra-segment share, defined as the market share of product j in market t within product j's segment. ξ_{jt} is the vehicle characteristics unobserved by the econometricians but considered by the consumers and the manufacturers.

[29] The variable 'Old Model' will be discussed below.

Due to the endogeneity issue of the price, I follow Berry et al. (1995) to construct the instrumental variables, commonly known as 'BLP IVs' (Nevo, 2000).

Estimation Results

Before I report the estimation results, I spend some words to explain the variable 'Old Model'. The variable 'Old Model' is a numerical variable I construct for this estimation. Note that most of the trims in my dataset are available for sales for only dozens of months. The variable 'Old Model' is constructed to indicate how old a trim is, according to where it is located in its life-cycle. For example, a trim of Acura MDX is available for sales from January 2010 to December 2012. Then, an observation in July 2011 for this trim is in the middle of its life-cycle and thus it is assigned the value '50%'.

Table 23 reports the estimation results for the WTP estimation. The variable 'Log Price' and the variable 'Weight' are scaled to prevent too many digits in the estimates[30]. In Table 23, column (1) and (3) report the estimates for logit model, dropping the intra-segment share. Column (2) and (4) report the estimates for nested logit model. The column (1) and (2) are estimated by Ordinary Least Square, which might be subject to the issue of endogeneity of price. The column (3) and (4) are estimated by Instrumental Variable, using BLP IVs.

I use the results from column (4) for empirical calculations, since it addresses the endogeneity issue and its nested structure is more realistic in automobile market. Read from Table 22 column (4), we can see that the estimated coefficients for log price (in log of 10,000 RMB), weight (in tons) and engine power (in kW) are -7.971, 3.985 and 0.0589, respectively.

[30] The scaling is only done in this WTP estimation, not in the previous estimations like technology progress estimation.

Welfare Benefits from Fuel Savings

Table 24 and Table 25 report the welfare benefits from fuel savings due to the improvements in fuel economy. It is calculated as the present value of the multiplication of 1) reduction in fuel consumption level (in L/100 km), 2) average distance a vehicle travels over its lifetime (in km), and 3) average social costs of gasoline in China (in RMB/L).

For the lifetime travel distance of a vehicle, I made the assumption that a vehicle travels 200,000 km over its lifetime. For the social costs of gasoline, I take into consideration the after-tax gasoline price, gasoline tax and externalities costs (GHG emissions, pollutants emissions, congestion and traffic accidents). The after-tax gasoline price is assumed to be 7.5RMB/L. The gasoline tax and externalities costs are taken from the estimates in Parry et al. (forthcoming), which are 0.30 USD/L and 0.70 USD/L, respectively. In their study, they estimated the gasoline taxes and externalities costs for China in 2010 as above. Based on these, I calculate the social costs for gasoline consumption in China to be 9.98 RMB/L (= 7.5 RMB/L - 0.3 USD/L * 6.2[31] + 0.7 USD/L * 6.2).

Since the fuel savings happen throughout the lifetime of a vehicle, I need to discount them back to the current period. I assume that the lifetime of a vehicle is 10 years and fuel savings are distributed evenly throughout the lifetime of a vehicle. Also, I assume that the discount rate is 10 percent. Thus, the results in Table 24 and Table 25 are interpreted as the present value of the future fuel savings.

For example, in Table 24, in the scenario of 2 percent yearly technology progress and no changes in weight and engine power, the discounted fuel savings are RMB 5,656. It means that if a person purchases a typical vehicle in 2015, the improvements in fuel economy over the period from 2012 to 2015 will save this person money in fuel over the lifetime of this vehicle. The present values of the fuel savings are RMB 5,656.

[31] I use the exchange rate of USD to CNY of 1:6.2 in this calculation.

From Table 24 and Table 25, we could see that the discounted values of average fuel savings are from RMB 2,389 to RMB 11,654 (from RMB 5,218 to RMB 7,411 for most realistic scenarios) in the 2015 table and from RMB 6,372 to RMB 38,618(from RMB 14,291 to RMB 20,141 for most realistic scenarios) in the 2020 table. Compared with the average personal income in China and the sales-weighted average MSRP (163,760 RMB) in China, the fuel savings are quite significant.

Welfare Losses from 'Downsizing' in Vehicle Characteristics

Then, I calculate the welfare losses from 'downsizing' of weight and engine power. To calculate them, I need the average MSRP for a vehicle, since the variable 'Price' enters the equation as a log term, not a linear term. Based on the sales data, I calculate the sales-weighted average MSRP to be 163,760 RMB in 2012. The formula I use for this back-of-envelope calculation is as follows:

$$\begin{aligned}
&\text{WTP for change in vehicle characteristic (in RMB)} \\
&\qquad = \{\text{Exp}[\ln(\text{Sales weighted average MSRP}) - \text{ Change in vehicle characteristic} \\
&\qquad * \text{Estimated coefficient for vehicle characteristic} \\
&\qquad / \text{Estimated coefficient for log price}] - \text{Sales weighted average MSRP}\} * 10000
\end{aligned}$$

Then, the welfare losses are the sum of WTP from change in weight and WTP from change in engine power. Read form the formula, we could see that the welfare losses only depend on change in weight and engine power, not on the technology progress.

The welfare losses are not reported in this thesis. However, the welfare losses, together with welfares benefits, are reported in Table 26 and Table 27 as the net welfare benefits (i.e. benefits from fuel savings minus welfare losses from 'downsizing' in weight and engine power).

We could compare Table 26 and Table 27 with Table 24 and Table 25, on a scenario by scenario basis. As we can see in Table 26, after taking into consideration the welfare losses from 'downsizing' in weight and engine power, the net welfare benefits are reduced significantly. Let us focus on the most realistic scenarios for discussions. In the most realistic scenarios in the 2015 table and the 2020 table, the social welfare effects vary from RMB 20,581 to RMB negative 464,50 (for 2015) and from RMB 57,182 to RMB negative 101,877. Although the magnitude of the estimated welfare benefits and costs are open to the critics of future research, one of the important conclusions drawn from this analysis is that the welfare losses from ‘downsizing’ of weight and engine power are too huge to neglect in China.

Combine the net welfare benefits analysis with the compliance matrices in Table 21 and Table 22, we could further conclude that the option of seriously downsizing in weight and engine power is not a good idea since the welfare losses would be too huge to be compensated by fuel savings. Thus, if we assume that the objectives for 2015 and 2020 must be met, then the firms have to significantly speed up the technology progress.

Comparison of Fuel Savings and WTP for Fuel Economy

A by-product of the WTP estimation is the estimated coefficient for fuel consumption, that is, -0.00906. Based on the estimate, I could calculate consumers’ WTP for fuel consumption, and compare it with the calculated fuel savings in Table 24 and Table 25.

The comparisons could be interpreted as how myopic consumers are in their vehicle purchasing decisions. Economic theory suggests that for each dollar of discounted future fuel savings, consumers should be willing to pay exactly one dollar. However, the undervaluation of fuel savings in the real world is found by many researchers, known as ‘energy paradox’ (Bento et al., 2012). The paradox suggests that consumers fail to take into account the fuel savings they will eventually gain in future years by purchasing a more fuel-efficient vehicle. Whether the undervaluation do exists and to what extent the fuel savings are undervalued are important in the policy choice of CAFE standards and market-based policy tools like gasoline taxes (Bento et al., 2012). If consumers are willing to pay the ‘right’ price for fuel economy, it is more likely that market-based policy tools are better than CAFE standards. Otherwise, the CAFE standards will do a better job.

I calculate the WTP for change in fuel consumption in the same way as the WTP for change in weight and engine power. Table 28 and Table 29 report the results, and they are comparable to Table 24 and Table 25 on a scenario by scenario basis.

For example, for the most top-left scenario in the 2015 table, the fuel savings are RMB 2,389 (in Table 24) while the WTP for fuel economy is RMB 36 (in Table 28). Thus, the undervaluation of fuel economy among Chinese consumers is very significant. Only 1.5 percent of the discounted fuel savings are incorporated into the purchasing decisions made by Chinese consumers. Furthermore, from column (4) of Table 23, we could see that the estimated coefficient of log fuel consumption is not statistically significant. It means that statistically the WTP for fuel economy is zero. To answer the question why Chinese consumers are so myopic needs future research. Possibly one of the reasons is that the concept fuel economy just starts to gain attentions among Chinese consumers[32].

[32] Note that the disclosure policies just started to be effective in January 2010.

Chapter 8 Conclusions

CAFE regulations are becoming increasingly important across the world, since it has showed its effectiveness in improving the fuel economy of the road transports and large potential in reducing GHG emissions. As a result, more and more countries have established their CAFE standards, kept tightening the fuel economy targets and designing more complicated structures, and expanded to more and more segments (such as buses, medium-duty trucks and heavy-duty trucks).

Following the developed countries, China also enacted its passenger cars CAFE policy mix for the first time in 2004, and then kept tightening the standards in later phases and expanded the regulations into LDCV and HDCV segments. However, the academic research, economics research in particular, is inadequate on China CAFE regulations.

Previous research on China CAFE regulations focuses narrowly on one or two component in China's entire CAFE policy mix. This thesis expands that focus and provides a clear and comprehensive picture of China's entire CAFE policy mix. As the first purpose of this thesis, detailed policy analysis of China's entire CAFE policy mix, including CAFE standards, testing standards, labeling standards and disclosure policies, is done in Chapter 3. It provides useful background information for those who are interested in China CAFE regulations but are obstructed by the language barrier.

As the second purpose, this thesis exploits the latest methodology, which are first raised by Knittel (2009) and later developed by Klier and Linn (2013), to estimate the technology trade-offs and the technology progress for vehicles sold in China. In general, the estimated technology progress in China over the period from 2009 to 2012 is significant (roughly about 10 percent). For the technology trade-offs, it is estimated that for every 1 percent change in weight and engine power, fuel consumption will change by roughly 0.5 percent and 0.25 percent, respectively. Separate regressions are run for different segment groups, and the results suggest that there do exist heterogeneities in the technology trade-offs and the technology progress across segments. These evidences support the segment heterogeneity model, which assume a separate technology progress curve for each segment. The estimation results of the segment heterogeneity model suggest that the 'Luxury' segment has the faster technology progress while the 'Sports' segment lags behind in the technology progress. Furthermore, the modification of the baseline model also allows us to understand the heterogeneity across different manufacturers and countries. The results suggest that Chinese local brands have a lower level of technology progress and a slower pace of technology progress, relative to JV brands and imported brands. Since one of the motivations of China CAFE standards is to push these domestic brands to improve in fuel economy technology, these results provide a warning for the Chinese policy makers.

By utilizing the estimated technology trade-offs, the estimated technology progress and the sales volumes data in Chinese automotive market, this thesis further find that the actual realized technology progress (sales-weighted) is far less than the estimated technology progress from the production side (in which each trim has the same weight), probably due to the fact that sales is distributed towards less fuel-efficient models and that there is sales lag-effect in Chinese automotive market. Also, by assuming that engine power and weight kept constant at the 2009 level, two hypothetical fuel economy curves have been drawn to provide a clearer picture of what could have happened over the sample period.

This thesis also predicts the compliance feasibility of the objectives for 2015 and 2020 (The State Council of China, 2012) raised by Chinese government. From the sensitivity analysis, it is quite clear that significant technology progress and huge compromises in weight and engine power have to be made in order to meet these objectives.

Good things usually come with costs. For each scenario in the sensitivity analysis, the welfare benefits from the improvements in fuel economy (i.e. fuel savings) and the welfare losses from the 'downsizing' of weight and engine power are calculated, based on some reasonable assumptions (on gasoline price, gasoline taxes, externalities of gasoline consumption, lifetime usage of a vehicle and discounted factor) and the estimated WTP for weight and for engine power. A nested logit model is utilized to estimate

WTPs for vehicle characteristics, following Berry (1994). For comparisons, the results of the welfare analysis are shown in the similar formatting and presentation as the sensitivity analysis for compliance. The benefits from fuel savings are huge, compared with personal income and sales-weighted average MSRP in China. However in some scenarios, the costs are so overwhelming that the net welfare losses become negative. The conclusion is that the welfare losses are too huge to be compensated by fuel savings. Thus, to meet the objectives for 2015 and 2020 set by Chinese government, it is not a good idea to choose 'downsizing' in weight and engine power. Instead, firms should push themselves to speed up the technology progress significantly. The welfare analysis in this thesis is not complete, but it does provide some food for thoughts for the Chinese policy makers when they are designing the future phases of CAFE standards in the passenger car segment.

Based on the estimation results and the insights drawn from them, I raise the following policy suggestions for China's passenger cars CAFE regulations. Firstly, the policy maker should be more realistic when they set objectives for the future. As clearly seen from the empirical results, the objective for 2015 and 2020 are too difficult for firms to meet if they don't choose the costly option of seriously 'downsizing' in weight and engine power. Although these objectives are not mandatory[33], they should be realistic enough to provide firms with guidelines for fuel economy improvements.

Secondly, the policy maker should keep in mind the welfare losses from 'downsizing' in weight and engine power. The estimated WTP for weight and for engine power is huge in China. Although the fuel savings from improvements in fuel economy is also significant, after I subtract the welfare losses, in most scenarios the net welfare benefits become negative. The major reason is that the WTP for weight and for engine power is so huge that even a mild decrease in these characteristics needs a large compensation from fuel savings. To avoid these welfare losses, the policy maker should cooperate closely with the

[33] CAFE standards are mandatory and should be complied with on the corporate average level, while these objectives are not mandatory and they are objectives for the entire Chinese automotive industry as a whole.

manufacturers and the industry experts to design the realistic fuel consumption targets to prevent the serious ‘downsizing’ from happening.

Thirdly, the policy maker should educate consumers about the importance of fuel economy. The establishment of the fuel economy online database by China MIIT is a good start. However, the public disclosure of fuel economy just started in January 2010. So, a lot of work remains to be done to improve consumers’ awareness of importance of fuel economy. Also, from the empirical estimation of WTP for fuel economy, we know that Chinese consumers, on average, are only willing to pay RMB 15 for every RMB 1,000 fuel savings. The discrepancy is so huge and daunting to neglect.

Huge amount of work is left for future research in the area of China’s CAFE regulations. Till now, this area is quite like an unexploited land. As more and more accurate data on Chinese automotive market become available, future research will be less obstructed by the data issue.

China has already become the world’s largest automotive market. Thus, the improvements in Chinese fleets’ fuel economy have significant meanings for the global joint efforts against global warming. Thus, hopefully, more and more attentions from academia would be drawn on China CAFE regulations in the future. For those researchers interested in this area, I hope this thesis could provide some useful background information.

TABLES

Table 1 Relationship between Policy Tools and Three GHG Emission Factors

	Vehicle Stocks	Vehicle-Use Intensity	Fuel Economy	
			In-Use Vehicles	New Vehicle Markets
CAFE standards	Indirect	Indirect	Indirect	**Direct**
Gasoline taxes	Indirect	**Direct**	Indirect	Indirect
Pollutants emission standards	Indirect	Indirect	Indirect	Indirect
Highway tolls	Indirect	**Direct**	Indirect	Indirect
Vehicle purchase taxes	Indirect	Indirect	Indirect	**Direct**
Hybrid/electric technology subsidies in production and/or purchase	Indirect	Indirect	Indirect	**Direct**

Table 2 Matching between Classifications of Vehicles in China

<table>
<tr><th colspan="3">Motor Vehicles and Trailers Types--Terms and Definitions (GB/T 3730.1-2001)</th><th>Classification of Power-Driven Vehicles and Trailers (GB/T 15089-2001)</th><th>Passenger Cars, LDCVs and HDCVs</th><th>Segments Used in the Empirical Study</th></tr>
<tr><td rowspan="7">Cars</td><td colspan="2">Passenger Cars</td><td>M_1 vehicles</td><td>Passenger Cars(PCs)</td><td>Mini, Small, Compact, Medium, Medium & Large, Luxury, Sports, SUV, MPV</td></tr>
<tr><td rowspan="6">Commercial Cars</td><td rowspan="3">Buses</td><td>M_2 vehicles ≤ 3,500 kg</td><td>Light-Duty Commercial Vehicles(LDCVs)</td><td>Light Bus</td></tr>
<tr><td>M_2 vehicles ≥ 3,500 kg</td><td rowspan="2">Heavy-Duty Commercial Vehicles(HDCVs)</td><td rowspan="2">N/A</td></tr>
<tr><td>M_3 vehicles</td></tr>
<tr><td rowspan="3">Goods Vehicles, Semi-Trailer Towing Vehicles</td><td>N_1 vehicles</td><td>Light-Duty Commercial Vehicles(LDCVs)</td><td>Pickup, Mini Truck, Mini Van</td></tr>
<tr><td>N_2 vehicles</td><td rowspan="2">Heavy-Duty Commercial Vehicles(HDCVs)</td><td rowspan="3">N/A</td></tr>
<tr><td>N_3 vehicles</td></tr>
<tr><td colspan="3">Trailers</td><td>O_1 vehicles, O_2 vehicles, O_3 vehicles, O_4 vehicles</td><td>N/A</td></tr>
<tr><td colspan="3">Combination Vehicles</td><td>N/A</td><td>N/A</td><td>N/A</td></tr>
</table>

Table 3 Structure and Development of China CAFE Standards and Testing Methods

		CAFE Standards	Release Date	Effective Date	Testing Methods
'PCs' or M_1 vehicles ≤ 3,500 kg	**Phase I**	Limits of Fuel Consumption for Passenger Cars (GB 19578-2004)	2004/09/02	2005/07/01 (new models) 2006/07/01 (old models)	Measurement Methods of Fuel Consumption for Light-Duty Vehicles (GB/T 19233-2003)
	Phase II			2008/01/01 (new models) 2009/01/01 (old models)	
	Phase III	Fuel Consumption Evaluation Methods and Targets for Passenger Cars (GB 27999-2011)	2011/12/30	2012/07/01	Measurement Methods of Fuel Consumption for Light-Duty Vehicles (GB/T 19233-2008)
	Phase IV	Expected to be fully effective in 2020 and with a phase-in period before 2020			
'LDCVs' or M_2 vehicles ≤ 3,500 kg and N_1 vehicles[34]	**Phase I**	Limits of Fuel Consumption for Light Duty Commercial Vehicle (GB 20997-2007)	2007/07/19	2008/02/01 (new models) 2009/01/01 (old models)	Measurement Methods of Fuel Consumption for Light-Duty Vehicles (GB/T 19233-2003)
	Phase II			2008/02/01 (new models) 2011/01/01 (old models)	
	Phase III	Expected to be effective in 2015			
'HDCVs' or M_2 vehicles ≥ 3,500 kg, M_3 vehicles, N_2 vehicles and N_3 vehicles[35]	**Phase I**	Fuel Consumption Limits for Heavy-Duty Commercial Vehicles (QC/T 924-2011)	2011/12/31	2012/07/01 (new models) 2014/07/01 (old models)	Fuel Consumption Test Methods for Heavy-Duty Commercial Vehicles (GB/T 27840-2011)
	Phase II	Expected to be effective in 2014/07/01 (new models) Expected to be effective in 2015/07/01 (old models)			

[34] All N_1 vehicles are less than 3,500 kg, by definition.
[35] All M_3 vehicles, N_2 vehicles and N_3 vehicles are greater than 3,500 kg, by definition.

Table 4 Development of Labeling Standards and Disclosure Policies

<table>
<tr><th></th><th></th><th>Passenger Cars and LDCVs</th><th>HDCVs</th></tr>
<tr><td rowspan="2">Labeling Standards</td><td>Effective Date</td><td>2010/01/01</td><td rowspan="3">Under Discussion</td></tr>
<tr><td>National Standard</td><td>Fuel Consumption Label for Light Vehicles
(GB 22757-2008)</td></tr>
<tr><td>Disclosure Policies</td><td>Effective Date</td><td>2010/01/01</td></tr>
</table>

Table 5 'First Paradigm' of China CAFE Standards

	Groups	Classes by…	Number of Classes	Special Rules
Passenger Cars Phase I	Baseline Version	Curb Weight	16	1) Not applicable to vehicles weighing more than 3,500 kg 2) Not applicable to alcohol-only vehicles 3) Not applicable to natural-gas-only vehicles 4) Not applicable to imported vehicles
	Special Structure (AT, ≥ 3 Rows or SUV)			
Passenger Cars Phase II	Baseline Version			
	Special Structure (AT, ≥ 3 Rows or SUV)			
LDCVs Phase I	N_1 vehicles Using Gasoline	Gross Vehicle Weight and Engine Displacement	11	1) 5% less strict for N_1 vehicles with fully closed van 2) 5% less strict for N_1 vehicles with tanker 3) 5% less strict for vehicles with auto transmission 4) 5% less strict for vehicles with all-wheel drive
	N_1 vehicles Using Diesel		11	
	M_2 vehicles ≤ 3,500 kg Using Gasoline		7	
	M_2 vehicles ≤ 3,500 kg Using Diesel		4	
LDCVs Phase I	N_1 vehicles Using Gasoline		11	
	N_1 vehicles Using Diesel		11	
	M_2 vehicles ≤ 3,500 kg Using Gasoline		7	
	M_2 vehicles ≤ 3,500 kg Using Diesel		4	
HDCVs Phase I	Goods Vehicles Using Gasoline	Gross Vehicle Weight	11	1) Not applicable to special goods vans 2) Not applicable to special goods tankers 3) Not applicable to special goods special tippers 4) Not applicable to special goods box/stake trucks 5) Not applicable to special goods crane/lift trucks 6) Not applicable to special goods special construction vehicles 7) Not applicable to tippers 8) Not applicable to city-buses
	Goods Vehicles Using Diesel			
	Semi-Trailer Towing Vehicles		8	
	Buses Using Gasoline		12	
	Buses Using Diesel			

Table 6 'Second Paradigm' of China CAFE Standards

	Groups	Classes by…	Number of Classes	Special Rules
Passenger Cars Phase III	Baseline Version	Curb Weight	16	1) Not applicable to vehicles weighing more than 3,500 kg 2) Not applicable to alcohol-only vehicles 3) Not applicable to natural-gas-only vehicles
	Special Structure (AT or ≥ 3 Rows)			

Table 7 China vs. US in CAFE Standards

	China Passenger Cars CAFE Standards			US Passenger Cars & Light Trucks CAFE Standards	
	Phase I	**Phase II**	**Phase III**	**Phase I**	**Phase II**
Release Date	Sep 2004		Dec 2011	1975	First enacted in 2007 Tightened in 2009
Effective Date	Jul 2005/Jul 2006	Jan 2008/Jan 2009	Jul 2012	MY 1978	MY 2011
Measurement of Fuel Economy	L/100 km			MPG	
Phase-in Period	No Phase-in Periods		2012-2014	Gradually increase stringency	Gradually increase stringency
Punishment	Stop Production for Unqualified Models		Not Released	Initially $5 for 0.1 MPG per vehicle, increased to $5.5 later	
Differences in Target Fuel Economy Levels	(Models are) subject to different targets, according to its group and its curb weight class			All cars are subject one target, while all light trucks are subject to another target	(Models are) subject to different targets, according to its 'footprint' group
Regulation Approach	Model Level		Corporate Average Level	Segment (Passenger Car/Light Truck) Level	Corporate Average Level
Transfer of Credits	No		Year	Year	Year & Firm

Table 8 Baseline Estimation for Trade-Offs, only Passenger Cars Included in Sample, Cobb-Douglas Functional Form

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined	(3) ln_fc_combined	(4) ln_fc_combined
ln_enginepower	0.224***	0.202***	0.271***	0.205***
	(0.00881)	(0.00846)	(0.00967)	(0.00709)
ln_weight	0.489***	0.558***	0.407***	0.479***
	(0.0182)	(0.0140)	(0.0198)	(0.0129)
_Isalesstar_2009	Baseline Year	Baseline Year	Baseline Year	Baseline Year
_Isalesstar_2010	-0.0155***	-0.0140***	-0.0285***	-0.0299***
	(0.00454)	(0.00467)	(0.00427)	(0.00501)
_Isalesstar_2011	-0.0554***	-0.0540***	-0.0708***	-0.0660***
	(0.00462)	(0.00477)	(0.00456)	(0.00530)
_Isalesstar_2012	-0.0795***	-0.0788***	-0.106***	-0.105***
	(0.00452)	(0.00465)	(0.00440)	(0.00507)
_Isalesstar_2013	-0.0931***	-0.0911***	-0.119***	-0.121***
	(0.00462)	(0.00473)	(0.00444)	(0.00505)
Turbocharger	Yes	Yes	No	No
Fuel Type	Yes	Yes	No	No
Fuel Injection Type	Yes	Yes	No	No
Hybrid	Yes	Yes	No	No
Number of Speeds	Yes	Yes	No	No
Transmission Type	Yes	Yes	No	No
Drive Wheel Type	Yes	Yes	No	No
Brand	Yes	Yes	Yes	No
Segment	Yes	No	Yes	No
Constant	-3.116***	-3.460***	-2.094***	-2.297***
	(0.166)	(0.147)	(0.123)	(0.0683)
Observations	4,280	4,280	5,356	5,356
Adjusted R-squared	0.907	0.900	0.818	0.724

Table 9 Baseline Estimation for Trade-Offs, All Observations Included in Sample, Cobb-Douglas Functional Form

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined	(3) ln_fc_combined	(4) ln_fc_combined
ln_enginepower	0.0284	0.00229	0.480***	0.389***
	(0.0189)	(0.0189)	(0.0137)	(0.0112)
ln_weight	0.432***	0.524***	0.529***	0.661***
	(0.0181)	(0.0142)	(0.0193)	(0.0138)
ln_torque	0.221***	0.223***	-0.290***	-0.295***
	(0.0209)	(0.0213)	(0.0141)	(0.0131)
_Isalesstar_2009	Baseline Year	Baseline Year	Baseline Year	Baseline Year
_Isalesstar_2010	-0.0131***	-0.0115**	-0.0254***	-0.0255***
	(0.00466)	(0.00477)	(0.00413)	(0.00489)
_Isalesstar_2011	-0.0490***	-0.0461***	-0.0712***	-0.0616***
	(0.00477)	(0.00489)	(0.00444)	(0.00517)
_Isalesstar_2012	-0.0736***	-0.0715***	-0.102***	-0.0971***
	(0.00466)	(0.00476)	(0.00425)	(0.00492)
_Isalesstar_2013	-0.0855***	-0.0831***	-0.115***	-0.113***
	(0.00478)	(0.00486)	(0.00432)	(0.00496)
Turbocharger	Yes	Yes	No	No
Fuel Type	Yes	Yes	No	No
Fuel Injection Type	Yes	Yes	No	No
Hybrid	Yes	Yes	No	No
Number of Speeds	Yes	Yes	No	No
Transmission Type	Yes	Yes	No	No
Drive Wheel Type	Yes	Yes	No	No
Brand	Yes	Yes	Yes	No
Segment	Yes	No	Yes	No
Constant	-3.015***	-3.528***	-2.419***	-2.916***
	(0.168)	(0.152)	(0.116)	(0.0688)
Observations	4,563	4,563	5,681	5,681
Adjusted R-squared	0.896	0.888	0.821	0.723

Table 10 Baseline Estimation for Trade-Offs, only Passenger Cars Included in Sample, Tranlog Functional Form

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined	(3) ln_fc_combined	(4) ln_fc_combined
ln_enginepower	-0.181	-0.176	-3.096***	-1.343***
	(0.276)	(0.274)	(0.317)	(0.254)
ln_weight	1.139*	0.853	6.129***	2.860***
	(0.649)	(0.605)	(0.768)	(0.590)
ln_weight_sq	0.00363	0.0280	-0.536***	-0.187***
	(0.0571)	(0.0551)	(0.0667)	(0.0512)
ln_enginepower_sq	0.145***	0.140***	-0.00231	0.0882***
	(0.0166)	(0.0167)	(0.0186)	(0.0134)
ln_weight_enginepower	-0.139**	-0.136**	0.458***	0.0897**
	(0.0541)	(0.0540)	(0.0610)	(0.0449)
_Isalesstar_2009	Baseline Year	Baseline Year	Baseline Year	Baseline Year
_Isalesstar_2010	-0.0181***	-0.0154***	-0.0285***	-0.0291***
	(0.00445)	(0.00457)	(0.00420)	(0.00494)
_Isalesstar_2011	-0.0558***	-0.0532***	-0.0707***	-0.0636***
	(0.00452)	(0.00466)	(0.00448)	(0.00523)
_Isalesstar_2012	-0.0796***	-0.0783***	-0.104***	-0.101***
	(0.00443)	(0.00455)	(0.00433)	(0.00500)
_Isalesstar_2013	-0.0935***	-0.0898***	-0.117***	-0.114***
	(0.00453)	(0.00463)	(0.00437)	(0.00499)
Turbocharger	Yes	Yes	No	No
Fuel Type	Yes	Yes	No	No
Fuel Injection Type	Yes	Yes	No	No
Hybrid	Yes	Yes	No	No
Number of Speeds	Yes	Yes	No	No
Transmission Type	Yes	Yes	No	No
Drive Wheel Type	Yes	Yes	No	No
Brand	Yes	Yes	Yes	No
Segment	Yes	No	Yes	No
Constant	-4.601**	-3.795**	-15.14***	-7.463***
	(1.943)	(1.723)	(2.318)	(1.708)
Observations	4,280	4,280	5,356	5,356
Adjusted R-squared	0.910	0.904	0.825	0.732

Table 11 Baseline Estimation for Trade-Offs, All Observations Included in Sample, Translog Functional Form

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined	(3) ln_fc_combined	(4) ln_fc_combined
ln_enginepower	-1.416***	-1.709***	-1.058**	1.098**
	(0.435)	(0.441)	(0.483)	(0.446)
ln_weight	2.106***	1.217*	3.624***	1.837***
	(0.706)	(0.629)	(0.817)	(0.684)
ln_torque	0.512	1.081**	-1.329**	-2.532***
	(0.509)	(0.519)	(0.575)	(0.567)
ln_weight_sq	-0.148**	-0.0628	-0.366***	-0.146**
	(0.0664)	(0.0609)	(0.0769)	(0.0674)
ln_torque_sq	-0.320***	-0.336***	-0.750***	-0.730***
	(0.0767)	(0.0785)	(0.0704)	(0.0699)
ln_enginepower_sq	-0.0420	-0.0746	-0.333***	-0.204***
	(0.0624)	(0.0638)	(0.0464)	(0.0431)
ln_weight_enginepower	-0.0604	-0.0190	-0.165*	-0.599***
	(0.0819)	(0.0827)	(0.0927)	(0.0850)
ln_weight_torque	0.152	0.0656	0.573***	0.723***
	(0.101)	(0.103)	(0.116)	(0.116)
ln_enginepower_torque	0.425***	0.476***	1.066***	1.024***
	(0.131)	(0.134)	(0.105)	(0.103)
_Isalesstar_2009	Baseline Year	Baseline Year	Baseline Year	Baseline Year
_Isalesstar_2010	-0.0148***	-0.0115**	-0.0263***	-0.0250***
	(0.00454)	(0.00463)	(0.00399)	(0.00467)
_Isalesstar_2011	-0.0490***	-0.0449***	-0.0697***	-0.0589***
	(0.00465)	(0.00476)	(0.00429)	(0.00493)
_Isalesstar_2012	-0.0727***	-0.0699***	-0.0987***	-0.0943***
	(0.00454)	(0.00463)	(0.00411)	(0.00469)
_Isalesstar_2013	-0.0841***	-0.0797***	-0.112***	-0.105***
	(0.00465)	(0.00473)	(0.00418)	(0.00474)
Turbocharger	Yes	Yes	No	No
Fuel Type	Yes	Yes	No	No
Fuel Injection Type	Yes	Yes	No	No
Hybrid	Yes	Yes	No	No
Number of Speeds	Yes	Yes	No	No
Transmission Type	Yes	Yes	No	No
Drive Wheel Type	Yes	Yes	No	No
Brand	Yes	Yes	Yes	No
Segment	Yes	No	Yes	No
Constant	-6.545***	-4.394**	-7.427***	-3.093*
	(1.999)	(1.718)	(2.296)	(1.800)
Observations	4,563	4,563	5,681	5,681
Adjusted R-squared	0.901	0.895	0.833	0.749

Table 12 By Segments: Baseline Estimation for Trade-Offs, only Passenger Cars Included in Sample, Cobb-Douglas Functional Form, All Fixed Effects Included

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined	(3) ln_fc_combined	(4) ln_fc_combined	(5) ln_fc_combined	(6) ln_fc_combined
ln_enginepower	0.116***	0.281***	0.242***	0.170***	0.313***	0.243***
	(0.0149)	(0.0302)	(0.0187)	(0.0356)	(0.0397)	(0.0171)
ln_weight	0.425***	0.525***	0.440***	0.377***	0.204	0.430***
	(0.0255)	(0.0987)	(0.0806)	(0.0705)	(0.126)	(0.0303)
_Isalesstar_2009	Baseline Year	Baseline Year	Baseline Year	Baseline Year	Baseline Year	Baseline Year
_Isalesstar_2010	-0.0219***	0.00966	0.00570	-0.0304**	-0.0185	-0.0502***
	(0.00648)	(0.0175)	(0.0100)	(0.0144)	(0.0224)	(0.0113)
_Isalesstar_2011	-0.0667***	-0.00738	-0.0551***	-0.0300*	-0.0525***	-0.0825***
	(0.00673)	(0.0181)	(0.00910)	(0.0159)	(0.0159)	(0.0112)
_Isalesstar_2012	-0.0869***	-0.0370**	-0.0547***	-0.0559***	-0.0102	-0.120***
	(0.00654)	(0.0150)	(0.00926)	(0.0163)	(0.0175)	(0.0112)
_Isalesstar_2013	-0.105***	-0.0970***	-0.0765***	-0.0707***	-0.0421	-0.104***
	(0.00662)	(0.0166)	(0.0101)	(0.0155)	(0.0278)	(0.0115)
Turbocharger	Yes	Yes	Yes	Yes	Yes	Yes
Fuel Type	Yes	Yes	Yes	Yes	Yes	Yes
Fuel Injection Type	Yes	Yes	Yes	Yes	Yes	Yes
Hybrid	Yes	Yes	Yes	Yes	Yes	Yes
Number of Speeds	Yes	Yes	Yes	Yes	Yes	Yes
Transmission Type	Yes	Yes	Yes	Yes	Yes	Yes
Drive Wheel Type	Yes	Yes	Yes	Yes	Yes	Yes
Brand	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-1.877***	-3.547***	-2.360***	-1.422***	0.397	-2.323***
	(0.204)	(0.679)	(0.550)	(0.515)	(0.925)	(0.221)
Observations	1,817	300	676	285	118	1,084
Adjusted R-squared	0.778	0.864	0.851	0.943	0.973	0.901
Samples Includes	Compact, Small, Mini	Luxury, Medium & Large	Medium	MPV	Sports	SUV

Table 13 By Segments: Baseline Estimation for Trade-Offs, only Passenger Cars Included in Sample, Cobb-Douglas Functional Form, Some Fixed Effects Included

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined	(3) ln_fc_combined	(4) ln_fc_combined	(5) ln_fc_combined	(6) ln_fc_combined
ln_enginepower	0.114***	0.336***	0.301***	0.226***	0.427***	0.358***
	(0.0155)	(0.0359)	(0.0243)	(0.0352)	(0.0526)	(0.0185)
ln_weight	0.421***	0.133	0.176*	0.388***	0.600***	0.293***
	(0.0278)	(0.109)	(0.102)	(0.0797)	(0.149)	(0.0326)
_Isalesstar_2009	Baseline Year	Baseline Year	Baseline Year	Baseline Year	Baseline Year	Baseline Year
_Isalesstar_2010	-0.0239***	-0.0621***	-0.0277***	-0.0496***	-0.0474*	-0.0228**
	(0.00533)	(0.0191)	(0.0103)	(0.0137)	(0.0251)	(0.00999)
_Isalesstar_2011	-0.0699***	-0.0504***	-0.0838***	-0.0851***	-0.0366*	-0.0544***
	(0.00587)	(0.0191)	(0.00993)	(0.0147)	(0.0218)	(0.0105)
_Isalesstar_2012	-0.0978***	-0.0983***	-0.114***	-0.118***	-0.0532**	-0.107***
	(0.00562)	(0.0160)	(0.0102)	(0.0152)	(0.0233)	(0.0104)
_Isalesstar_2013	-0.109***	-0.163***	-0.147***	-0.112***	0.00402	-0.0778***
	(0.00564)	(0.0178)	(0.0109)	(0.0145)	(0.0348)	(0.0106)
Brand	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-1.461***	-0.264	-0.548	-1.876***	-4.520***	-1.358***
	(0.154)	(0.705)	(0.678)	(0.540)	(0.895)	(0.217)
Observations	2,329	365	882	348	133	1,299
Adjusted R-squared	0.640	0.702	0.596	0.917	0.923	0.782
Samples Includes	Compact, Small, Mini	Luxury, Medium & Large	Medium	MPV	Sports	SUV

Table 14 Segment Heterogeneity Estimation for Trade-Offs, only Passenger Cars Included in Sample, Cobb-Douglas Functional Form

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined	(3) ln_fc_combined
ln_enginepower	0.226***	0.264***	0.244***
	(0.00879)	(0.00968)	(0.00832)
ln_weight	0.496***	0.423***	0.363***
	(0.0181)	(0.0199)	(0.0173)
Turbocharger	Yes	No	No
Fuel Type	Yes	No	No
Fuel Injection Type	Yes	No	No
Hybrid	Yes	No	No
Number of Speeds	Yes	No	No
Transmission Type	Yes	No	No
Drive Wheel Type	Yes	No	No
Brand	Yes	Yes	No
Segment-Sales Start Year Interactions	Yes	Yes	Yes
Constant	-3.126***	-2.262***	-1.754***
	(0.167)	(0.125)	(0.105)
Observations	4,280	5,356	5,356
Adjusted R-squared	0.909	0.823	0.747

Table 15 Segment Heterogeneity Estimation for Trade-Offs, only Passenger Cars Included in Sample, Translog Functional Form

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined	(3) ln_fc_combined
ln_enginepower	-0.155	-3.099***	-2.122***
	(0.277)	(0.318)	(0.268)
ln_weight	1.286**	5.994***	3.322***
	(0.655)	(0.772)	(0.657)
ln_weight_sq	-0.00929	-0.531***	-0.273***
	(0.0576)	(0.0671)	(0.0555)
ln_enginepower_sq	0.136***	-0.0154	0.0688***
	(0.0167)	(0.0187)	(0.0145)
ln_weight_enginepower	-0.130**	0.474***	0.226***
	(0.0545)	(0.0614)	(0.0483)
Turbocharger	Yes	No	No
Fuel Type	Yes	No	No
Fuel Injection Type	Yes	No	No
Hybrid	Yes	No	No
Number of Speeds	Yes	No	No
Transmission Type	Yes	No	No
Drive Wheel Type	Yes	No	No
Brand	Yes	Yes	No
Segment-Sales Start Year Interactions	Yes	Yes	Yes
Constant	-5.183***	-14.80***	-7.082***
	(1.969)	(2.328)	(2.020)
Observations	4,280	5,356	5,356
Adjusted R-squared	0.912	0.828	0.756

Table 16 Country Effects: Level, No Grouping

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined
ln_enginepower	0.221***	0.285***
	(0.00831)	(0.00883)
ln_weight	0.520***	0.365***
	(0.0163)	(0.0169)
_Isalesstar_2009	Baseline Year	Baseline Year
_Isalesstar_2010	-0.0127**	-0.0258***
	(0.00498)	(0.00458)
_Isalesstar_2011	-0.0578***	-0.0698***
	(0.00496)	(0.00485)
_Isalesstar_2012	-0.0830***	-0.102***
	(0.00486)	(0.00464)
_Isalesstar_2013	-0.0943***	-0.123***
	(0.00494)	(0.00466)
Turbocharger	Yes	No
Fuel Type	Yes	No
Fuel Injection Type	Yes	No
Hybrid	Yes	No
Number of Speeds	Yes	No
Transmission Type	Yes	No
Drive Wheel Type	Yes	No
Segment	Yes	Yes
China_CE	Baseline Country	Baseline Country
JVChina_CE	-0.00729	0.00116
	(0.0100)	(0.0131)
CzechRepublic_CE	0.0671	0.00220
	(0.0542)	(0.0730)
JVCzechRepublic_CE	-0.00442	-0.0372***
	(0.00802)	(0.00961)
France_CE	0.00471	0.0216*
	(0.0114)	(0.0122)
JVFrance_CE	0.0204***	0.0553***
	(0.00616)	(0.00739)
Germany_CE	-0.0486***	-0.114***
	(0.00627)	(0.00651)
JVGermany_CE	-0.0168***	-0.0835***
	(0.00562)	(0.00563)
Italy_CE	0.112***	0.0751***
	(0.0256)	(0.0283)
JVItaly_CE	0.0390	-0.00338
	(0.0296)	(0.0392)
Japan_CE	-0.0610***	-0.0629***
	(0.00667)	(0.00713)
JVJapan_CE	-0.0393***	-0.0216***
	(0.00421)	(0.00477)
Korea_CE	-0.0167*	-0.0410***
	(0.00973)	(0.0112)

JVKorea_CE	-0.0649***	-0.0405***
	(0.00647)	(0.00752)
Spain_CE	-0.0151	-0.149**
	(0.0444)	(0.0598)
Sweden_CE	-0.0187*	-0.0673***
	(0.00995)	(0.0115)
JVSweden_CE	0.0301*	0.0133
	(0.0157)	(0.0190)
JVTaiwan_CE	0.0396***	0.0290**
	(0.0114)	(0.0142)
UK_CE	0.000850	-0.0238**
	(0.0102)	(0.0105)
JVUK_CE	0.000464	0.0471***
	(0.0132)	(0.0164)
US_CE	-0.0505***	0.00618
	(0.00809)	(0.00921)
JVUS_CE	-0.0345***	-0.0265***
	(0.00520)	(0.00607)
Constant	-3.418***	-1.849***
	(0.151)	(0.1000)
Observations	4,280	5,356
Adjusted R-squared	0.876	0.774

Table 17 Country Effects: Level, with Grouping

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined
ln_enginepower	0.215***	0.282***
	(0.00798)	(0.00891)
ln_weight	0.545***	0.359***
	(0.0160)	(0.0171)
_Isalesstar_2009	Baseline Year	Baseline Year
_Isalesstar_2010	-0.0122**	-0.0331***
	(0.00511)	(0.00477)
_Isalesstar_2011	-0.0544***	-0.0720***
	(0.00507)	(0.00505)
_Isalesstar_2012	-0.0819***	-0.107***
	(0.00498)	(0.00483)
_Isalesstar_2013	-0.0915***	-0.124***
	(0.00506)	(0.00484)
Turbocharger	Yes	No
Fuel Type	Yes	No
Fuel Injection Type	Yes	No
Hybrid	Yes	No
Number of Speeds	Yes	No
Transmission Type	Yes	No
Drive Wheel Type	Yes	No
Segment	Yes	Yes
China_CE	Baseline Country	Baseline Country
Japan_CE	-0.0534***	-0.0537***
	(0.00680)	(0.00742)
Korea_CE	-0.0115	-0.0335***
	(0.00998)	(0.0117)
US_CE	-0.0459***	0.0139
	(0.00829)	(0.00959)
Europe_CE	-0.0298***	-0.0706***
	(0.00536)	(0.00588)
JointVenture_CoM	-0.0231***	-0.0252***
	(0.00332)	(0.00376)
Constant	-3.617***	-1.780***
	(0.153)	(0.101)
Observations	4,280	5,356
Adjusted R-squared	0.868	0.752

Table 18 Country Effects: Linear Trend in Year, No Grouping

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined
ln_enginepower	0.212***	0.273***
	(0.00826)	(0.00863)
ln_weight	0.535***	0.370***
	(0.0165)	(0.0169)
Turbocharge	Yes	No
Fuel Type	Yes	No
Fuel Injection Type	Yes	No
Hybrid	Yes	No
Number of Speeds	Yes	No
Transmission Type	Yes	No
Drive Wheel Type	Yes	No
Segment	Yes	Yes
China_CE_t	-0.0226***	-0.0254***
	(0.00116)	(0.00130)
JVChina_CE_t	-0.0224***	-0.0240***
	(0.00250)	(0.00324)
CzechRepublic_CE_t	-0.00649	-0.0246*
	(0.0110)	(0.0147)
JVCzechRepublic_CE_t	-0.0207***	-0.0342***
	(0.00227)	(0.00278)
France_CE_t	-0.0196***	-0.0167***
	(0.00312)	(0.00329)
JVFrance_CE_t	-0.0160***	-0.0104***
	(0.00174)	(0.00216)
Germany_CE_t	-0.0303***	-0.0543***
	(0.00166)	(0.00173)
JVGermany_CE_t	-0.0248***	-0.0479***
	(0.00162)	(0.00169)
Italy_CE_t	0.0329***	0.0239*
	(0.00971)	(0.0123)
JVItaly_CE_t	-0.0149**	-0.0282***
	(0.00726)	(0.00951)
Japan_CE_t	-0.0347***	-0.0426***
	(0.00196)	(0.00219)
JVJapan_CE_t	-0.0300***	-0.0298***
	(0.00130)	(0.00148)
Korea_CE_t	-0.0205***	-0.0302***
	(0.00261)	(0.00321)
JVKorea_CE_t	-0.0365***	-0.0339***
	(0.00194)	(0.00231)
Spain_CE_t	-0.0260**	-0.0639***
	(0.0113)	(0.0150)
Sweden_CE_t	-0.0255***	-0.0393***
	(0.00258)	(0.00316)
JVSweden_CE_t	-0.0131***	-0.0237***
	(0.00441)	(0.00570)

JVTaiwan_CE_t	-0.0109***	-0.0173***
	(0.00283)	(0.00352)
UK_CE_t	-0.0199***	-0.0310***
	(0.00305)	(0.00370)
JVUK_CE_t	-0.0282***	-0.0225***
	(0.00327)	(0.00431)
US_CE_t	-0.0308***	-0.0204***
	(0.00210)	(0.00253)
JVUS_CE_t	-0.0284***	-0.0308***
	(0.00148)	(0.00176)
Constant	-3.513***	-1.821***
	(0.152)	(0.0992)
Observations	4,280	5,356
Adjusted R-squared	0.872	0.771

Table 19 Country Effects: Linear Trend in Year, with Grouping

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined
ln_enginepower	0.208***	0.272***
	(0.00792)	(0.00868)
ln_weight	0.553***	0.361***
	(0.0162)	(0.0170)
Turbocharge	Yes	No
Fuel Type	Yes	No
Fuel Injection Type	Yes	No
Hybrid	Yes	No
Number of Speeds	Yes	No
Transmission Type	Yes	No
Drive Wheel Type	Yes	No
Segment	Yes	Yes
China_CE_t	-0.0227***	-0.0258***
	(0.00118)	(0.00135)
Japan_CE_t	-0.0333***	-0.0411***
	(0.00199)	(0.00227)
Korea_CE_t	-0.0193***	-0.0295***
	(0.00266)	(0.00333)
US_CE_t	-0.0297***	-0.0194***
	(0.00214)	(0.00262)
Europe_CE_t	-0.0269***	-0.0439***
	(0.00143)	(0.00157)
JointVenture_CoM_t	-0.0260***	-0.0314***
	(0.00106)	(0.00115)
Constant	-3.653***	-1.745***
	(0.154)	(0.100)
Observations	4,280	5,356
Adjusted R-squared	0.866	0.751

Table 20 Manufacturer Effects, Level, No Grouping

VARIABLES	(1) ln_fc_combined	(2) ln_fc_combined
ln_enginepower	0.243***	0.284***
	(0.00833)	(0.00911)
ln_weight	0.470***	0.384***
	(0.0174)	(0.0187)
_Isalesstar_2009	Baseline Year	Baseline Year
_Isalesstar_2010	-0.0185***	-0.0280***
	(0.00462)	(0.00444)
_Isalesstar_2011	-0.0612***	-0.0734***
	(0.00467)	(0.00470)
_Isalesstar_2012	-0.0856***	-0.107***
	(0.00460)	(0.00454)
_Isalesstar_2013	-0.0968***	-0.121***
	(0.00467)	(0.00459)
Turbocharger	Yes	No
Fuel Type	Yes	No
Fuel Injection Type	Yes	No
Hybrid	Yes	No
Number of Speeds	Yes	No
Transmission Type	Yes	No
Drive Wheel Type	Yes	No
Segment	Yes	Yes
Manufacturer	Yes	Yes
Constant	-3.446***	-1.754***
	(0.166)	(0.149)
Observations	4,280	5,356
Adjusted R-squared	0.898	0.796

Table 21 Compliance Matrix for Fuel Consumption in 2015

Unit: L/100km

Yearly Technology Progress	Yearly Change: W +1%; EP +2%	Yearly Change: W 0%; EP 0%	Yearly Change: W -1%; EP -3%	Yearly Change: W -2%; EP -6%	Yearly Change: W -3%; EP -9%	Yearly Change: W -4%; EP -12%
1.00%	7.492	7.456	7.420	7.384	7.349	7.313
1.25%	7.434	7.398	7.363	7.327	7.291	7.255
1.50%	7.376	7.341	7.305	7.269	7.233	7.198
1.75%	7.319	7.283	7.247	7.211	7.176	7.140
2.00%	**7.261**	**7.225**	**7.190**	**7.154**	**7.118**	**7.082**
2.25%	7.204	7.168	7.132	7.096	7.060	7.025
2.50%	7.146	7.110	7.074	7.039	7.003	6.967
2.75%	7.088	7.052	7.017	6.981	6.945	6.909
3.00%	7.031	6.995	6.959	6.923	6.887	6.852
3.25%	6.973	6.937	6.901	6.866	6.830	6.794
3.50%	6.915	6.879	6.844	6.808	6.772	6.736

Table 22 Compliance Matrix for Fuel Consumption in 2020

Unit: L/100km

Yearly Technology Progress	**Yearly Change: W +1%; EP +2%**	**Yearly Change: W 0%; EP 0%**	**Yearly Change: W -1%; EP -3%**	**Yearly Change: W -2%; EP -6%**	**Yearly Change: W -3%; EP -9%**	**Yearly Change: W -4%; EP -12%**
1.00%	7.167	7.072	6.976	6.881	6.785	6.690
1.35%	6.952	6.856	6.761	6.666	6.570	6.475
1.70%	6.737	6.641	6.546	6.450	6.355	6.260
2.05%	**6.521**	**6.426**	**6.331**	**6.235**	**6.140**	**6.044**
2.40%	6.306	6.211	6.115	6.020	5.925	5.829
2.75%	6.091	5.996	5.900	5.805	5.709	5.614
3.10%	5.876	5.780	5.685	5.590	5.494	5.399
3.45%	5.660	5.565	5.470	5.374	5.279	5.183
3.80%	5.445	5.350	5.254	5.159	5.064	4.968
4.15%	5.230	5.135	5.039	4.944	4.848	4.753
4.50%	5.015	4.919	4.824	4.729	4.633	4.538

Table 23 Logit and Nested Logit Regressions

VARIABLES SPECIFICATIONS	(1) dep Logit OLS	(2) dep Nested Logit OLS	(3) dep Logit IV	(4) dep Nested Logit IV
ln_price	-1.506***	-0.965***	0.0510	-7.971***
	(0.0282)	(0.0141)	(0.233)	(0.200)
fuelconsumption	0.0541***	-0.230***	0.00891	-0.00906
	(0.00649)	(0.00327)	(0.00942)	(0.00883)
weight	0.849***	0.949***	0.170	3.985***
	(0.0312)	(0.0155)	(0.106)	(0.0907)
enginepower	-0.000658**	0.00414***	-0.0130***	0.0589***
	(0.000329)	(0.000164)	(0.00186)	(0.00158)
oldmodel	-0.727***	0.322***	-0.723***	0.236***
	(0.0197)	(0.00997)	(0.0200)	(0.0191)
Manufacturer	Yes	Yes	Yes	Yes
ln_within_seg_share		0.782***		0.730***
		(0.00146)		(0.00315)
Constant	-10.95***	-7.384***	-13.72***	4.789***
	(0.347)	(0.173)	(0.543)	(0.476)
Observations	94,314	94,314	94,314	94,314
R-squared	0.323	0.833	0.301	0.392

Table 24 Welfare Benefits (i.e. Fuel Savings) of Improvements in Fuel Economy in 2015

Unit: RMB

Yearly Technology Progress	**Yearly Change: W +1%; EP +2%**	**Yearly Change: W 0%; EP 0%**	**Yearly Change: W -1%; EP -3%**	**Yearly Change: W -2%; EP -6%**	**Yearly Change: W -3%; EP -9%**	**Yearly Change: W -4%; EP -12%**
1.00%	2389	2828	3267	3706	4144	4583
1.25%	3096	3535	3974	4413	4852	5290
1.50%	3804	4242	4681	5120	5559	5997
1.75%	4511	4949	5388	5827	6266	6704
2.00%	**5218**	**5656**	**6095**	**6534**	**6973**	**7411**
2.25%	5925	6363	6802	7241	7680	8118
2.50%	6632	7070	7509	7948	8387	8826
2.75%	7339	7777	8216	8655	9094	9533
3.00%	8046	8485	8923	9362	9801	10240
3.25%	8753	9192	9630	10069	10508	10947
3.50%	9460	9899	10337	10776	11215	11654

Table 25 Welfare Benefits (i.e. Fuel Savings) of Improvements in Fuel Economy in 2020

Unit: RMB

Yearly Technology Progress	Yearly Change: W +1%; EP +2%	Yearly Change: W 0%; EP 0%	Yearly Change: W -1%; EP -3%	Yearly Change: W -2%; EP -6%	Yearly Change: W -3%; EP -9%	Yearly Change: W -4%; EP -12%
1.00%	6372	7542	8712	9882	11052	12222
1.35%	9011	10181	11351	12522	13692	14862
1.70%	11651	12821	13991	15161	16331	17501
2.05%	**14291**	**15461**	**16631**	**17801**	**18971**	**20141**
2.40%	16930	18100	19270	20440	21610	22780
2.75%	19570	20740	21910	23080	24250	25420
3.10%	22210	23380	24550	25720	26890	28060
3.45%	24849	26019	27189	28359	29529	30699
3.80%	27489	28659	29829	30999	32169	33339
4.15%	30128	31299	32469	33639	34809	35979
4.50%	32768	33938	35108	36278	37448	38618

Table 26 Net Welfare Benefits of Improvements in Fuel Economy in 2015

Unit: RMB

Yearly Technology Progress	Yearly Change: W +1%; EP +2%	Yearly Change: W 0%; EP 0%	Yearly Change: W -1%; EP -3%	Yearly Change: W -2%; EP -6%	Yearly Change: W -3%; EP -9%	Yearly Change: W -4%; EP -12%
1.00%	17753	2828	-11292	-24655	-37303	-49278
1.25%	18460	3535	-10585	-23948	-36596	-48571
1.50%	19167	4242	-9878	-23241	-35889	-47864
1.75%	19874	4949	-9171	-22534	-35182	-47157
2.00%	**20581**	**5656**	**-8464**	**-21827**	**-34475**	**-46450**
2.25%	21288	6363	-7757	-21120	-33768	-45743
2.50%	21995	7070	-7050	-20413	-33061	-45036
2.75%	22702	7777	-6343	-19706	-32354	-44329
3.00%	23409	8485	-5636	-18998	-31647	-43622
3.25%	24116	9192	-4929	-18291	-30940	-42915
3.50%	24823	9899	-4222	-17584	-30233	-42208

Table 27 Net Welfare Benefits of Improvements in Fuel Economy in 2020

Unit: RMB

Yearly Technology Progress	Yearly Change: W +1%; EP +2%	Yearly Change: W 0%; EP 0%	Yearly Change: W -1%; EP -3%	Yearly Change: W -2%; EP -6%	Yearly Change: W -3%; EP -9%	Yearly Change: W -4%; EP -12%
1.00%	49263	7542	-28450	-59549	-86464	-109796
1.35%	51903	10181	-25811	-56910	-83825	-107156
1.70%	54542	12821	-23171	-54270	-81185	-104517
2.05%	**57182**	**15461**	**-20531**	**-51630**	**-78546**	**-101877**
2.40%	59822	18100	-17892	-48991	-75906	-99238
2.75%	62461	20740	-15252	-46351	-73266	-96598
3.10%	65101	23380	-12612	-43712	-70627	-93958
3.45%	67740	26019	-9973	-41072	-67987	-91319
3.80%	70380	28659	-7333	-38432	-65347	-88679
4.15%	73020	31299	-4693	-35793	-62708	-86039
4.50%	75659	33938	-2054	-33153	-60068	-83400

Table 28 WTP for Fuel Economy in 2015

Unit: RMB

Yearly Technology Progress	Yearly Change: W +1%; EP +2%	Yearly Change: W 0%; EP 0%	Yearly Change: W -1%; EP -3%	Yearly Change: W -2%; EP -6%	Yearly Change: W -3%; EP -9%	Yearly Change: W -4%; EP -12%
1.00%	36	43	50	56	63	70
1.25%	47	54	60	67	74	80
1.50%	58	64	71	78	84	91
1.75%	68	75	82	88	95	102
2.00%	**79**	**86**	**93**	**99**	**106**	**113**
2.25%	90	97	103	110	117	123
2.50%	101	107	114	121	127	134
2.75%	111	118	125	131	138	145
3.00%	122	129	135	142	149	155
3.25%	133	140	146	153	160	166
3.50%	144	150	157	164	170	177

Table 29 WTP for Fuel Economy in 2020

Unit: RMB

Yearly Technology Progress	Yearly Change: W +1%; EP +2%	Yearly Change: W 0%; EP 0%	Yearly Change: W -1%; EP -3%	Yearly Change: W -2%; EP -6%	Yearly Change: W -3%; EP -9%	Yearly Change: W -4%; EP -12%
1.00%	97	114	132	150	168	186
1.35%	137	155	172	190	208	226
1.70%	177	195	212	230	248	266
2.05%	**217**	**235**	**253**	**270**	**288**	**306**
2.40%	257	275	293	311	328	346
2.75%	297	315	333	351	368	386
3.10%	337	355	373	391	409	426
3.45%	378	395	413	431	449	467
3.80%	418	436	453	471	489	507
4.15%	458	476	494	511	529	547
4.50%	498	516	534	552	569	587

FIGURES

Figure 1 Structure of China's CAFE Policy Mix

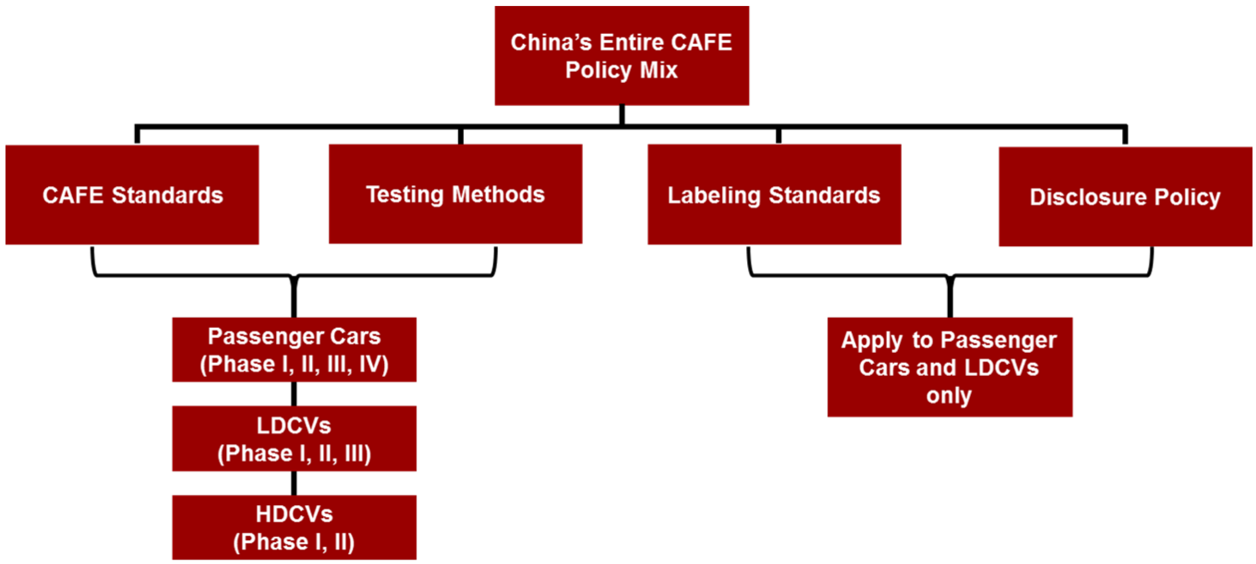


Figure 2 CAFE Standards in the 'First Paradigm'

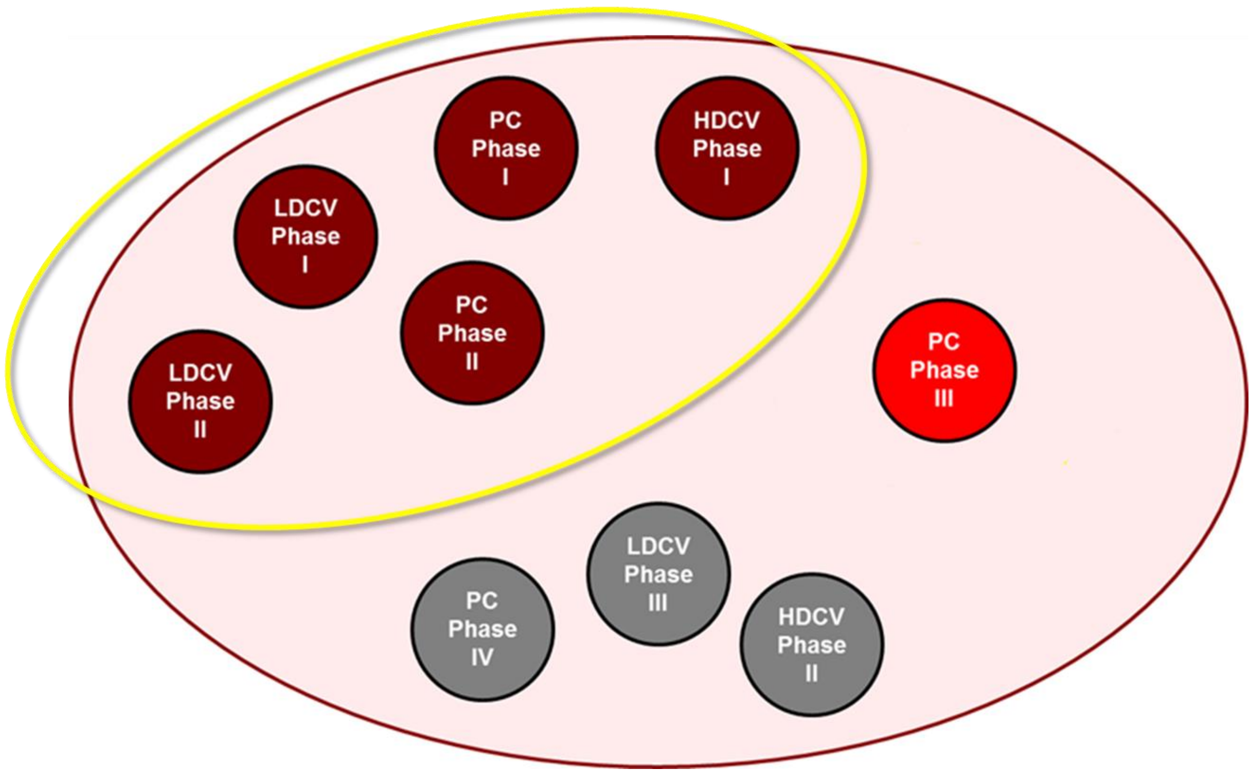


Figure 3 Maximum Limits and Targets in China Passenger Cars CAFE Standards

Unit: L/100km

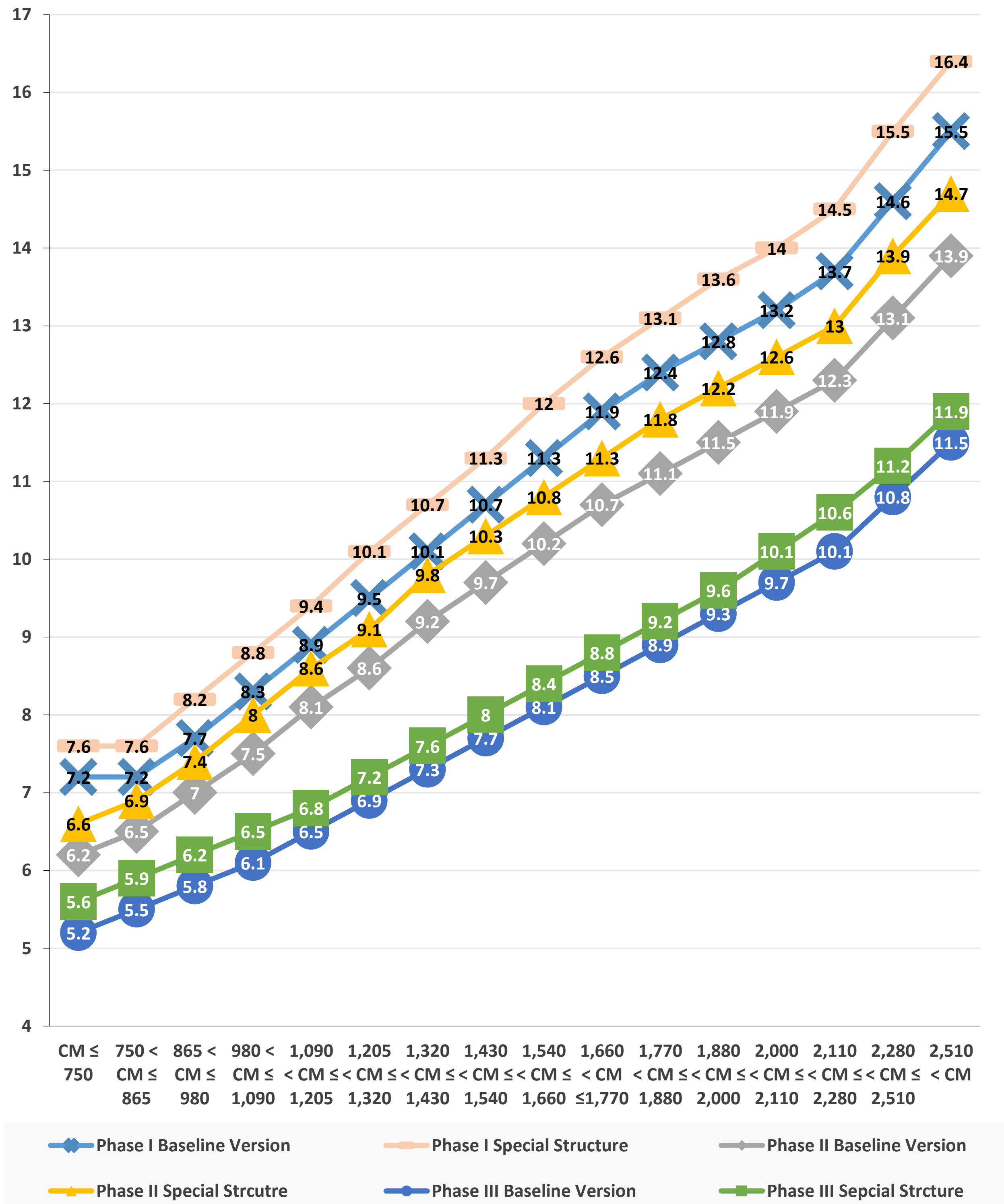


Figure 4 CAFE Standards in the 'Second Paradigm'

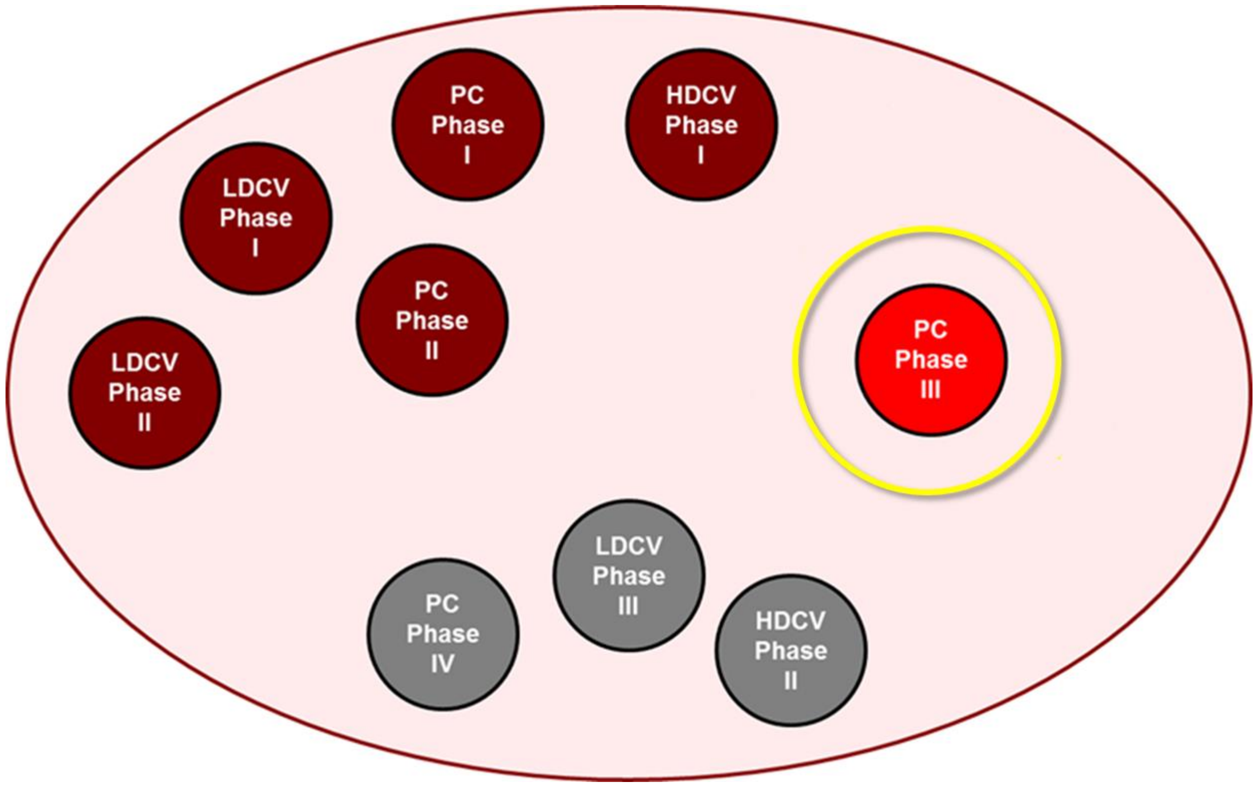


Figure 5 The Technology Frontier and the Technology Progress

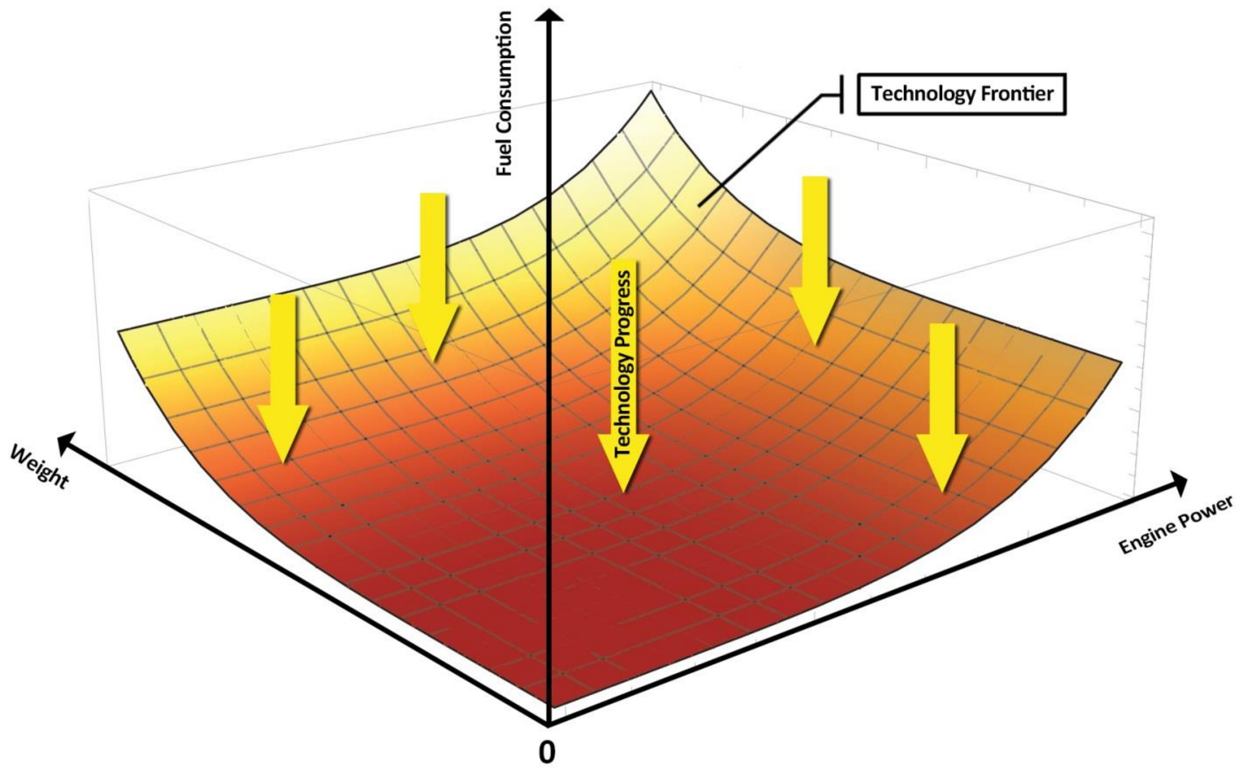


Figure 6 Segment Heterogeneity Estimation for 'Residual' Technology Progress, only Passenger Cars Included in Sample, Cobb-Douglas Functional Form

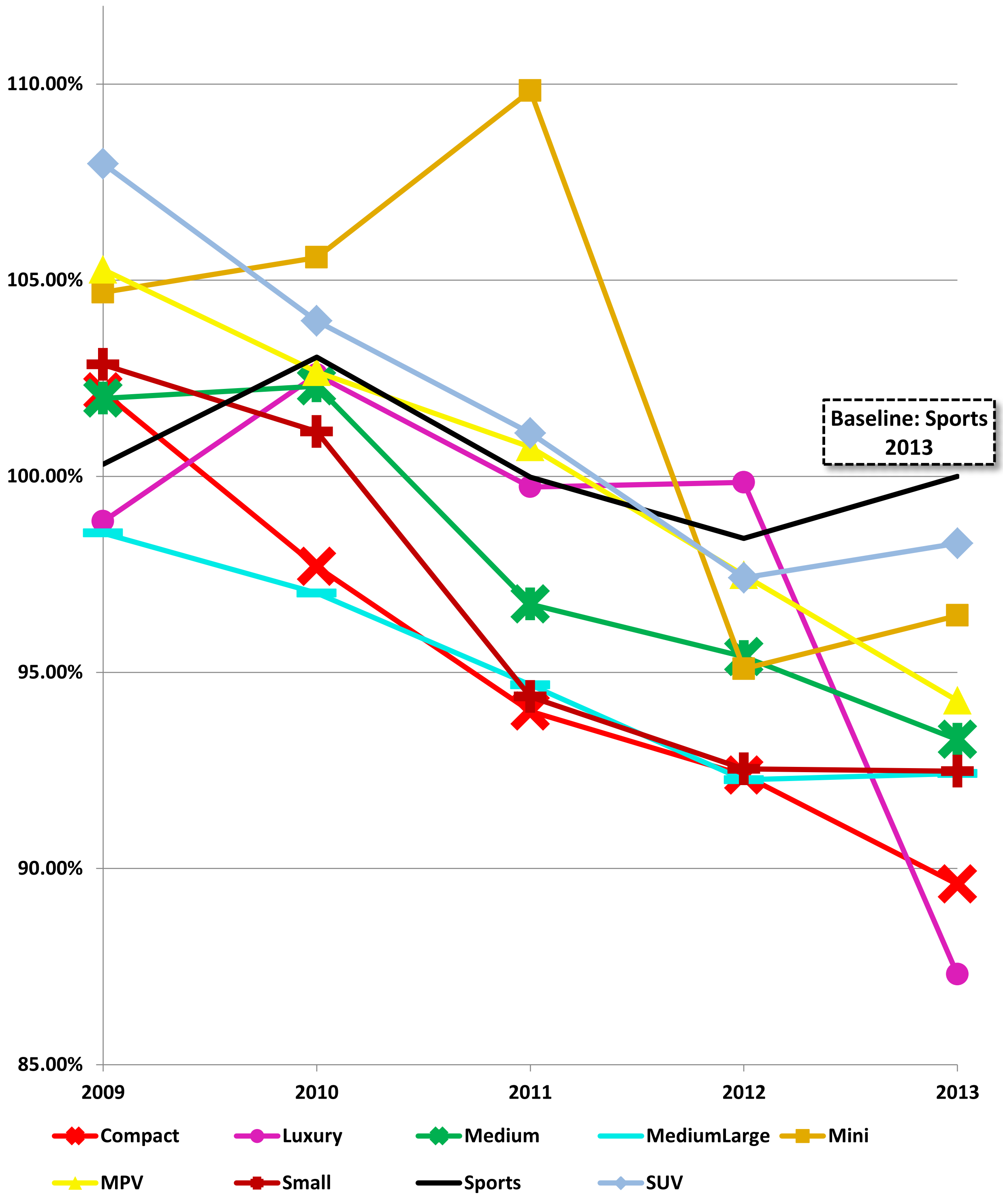


Figure 7 Segment Heterogeneity Estimation for 'Residual' Technology Progress, only Passenger Cars Included in Sample, Translog Functional Form

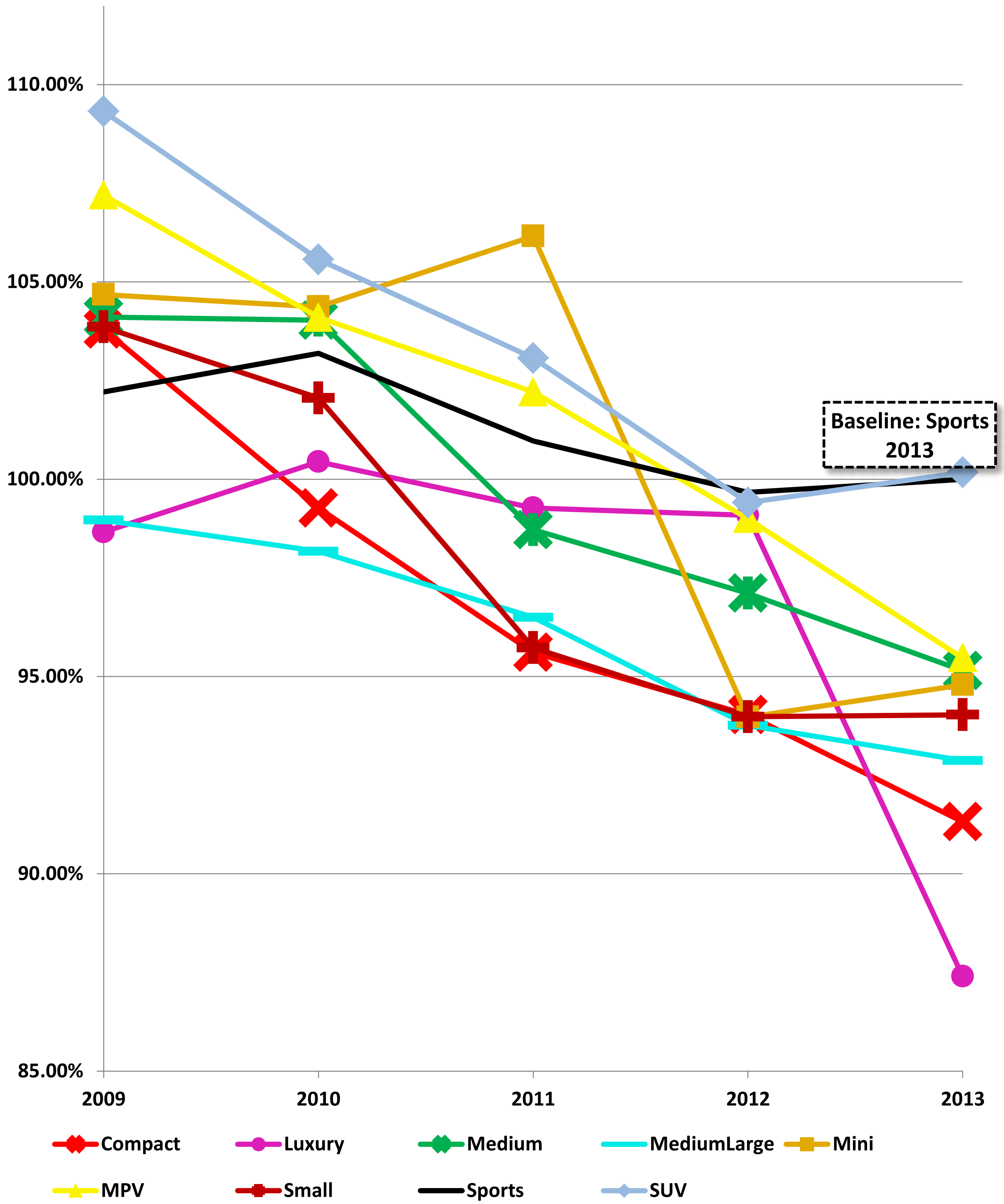


Figure 8 Segment Heterogeneity Estimation for 'Total' Technology Progress, only Passenger Cars Included in Sample, Cobb-Douglas Functional Form

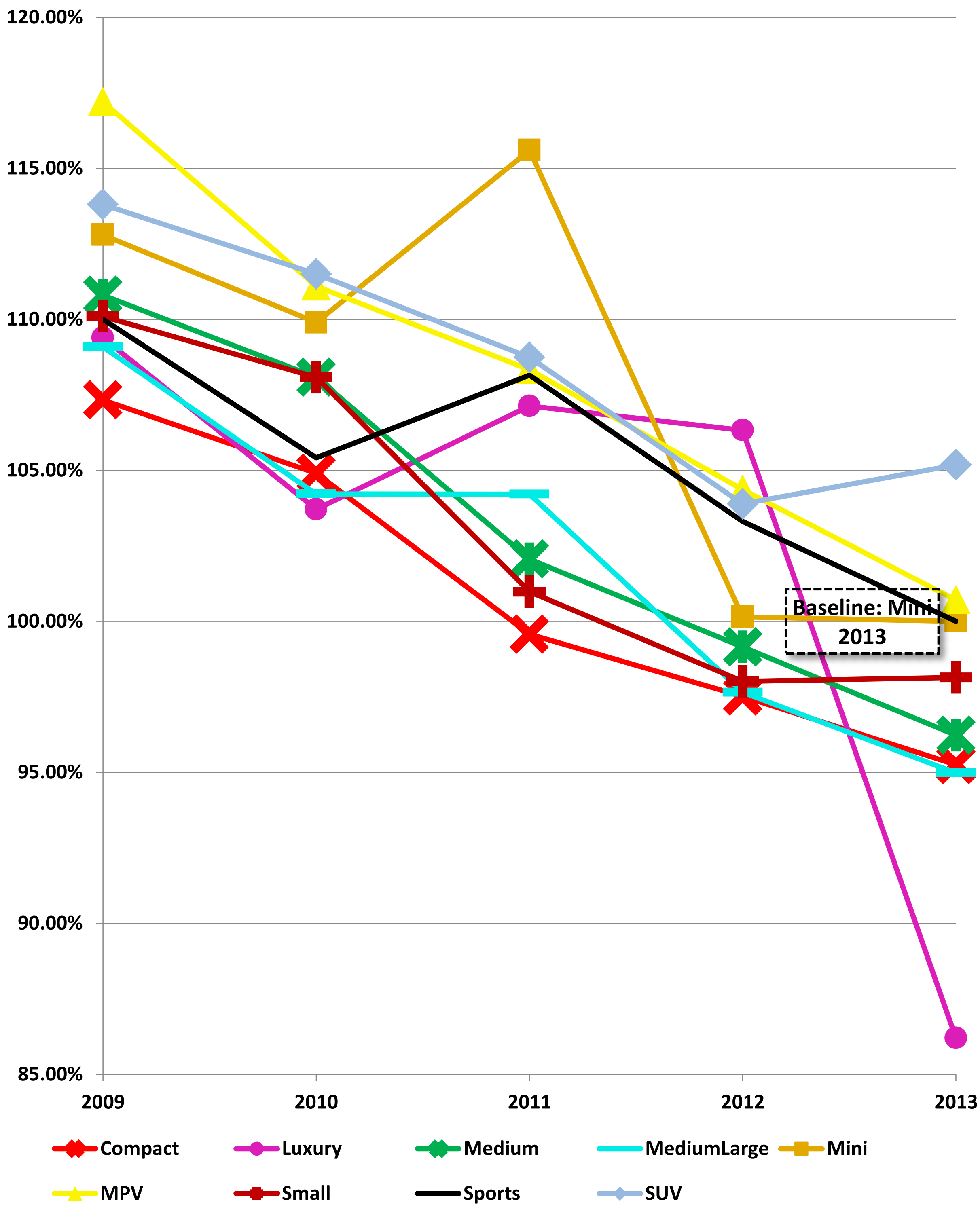


Figure 9 Segment Heterogeneity Estimation for 'Total' Technology Progress, only Passenger Cars Included in Sample, Translog Functional Form

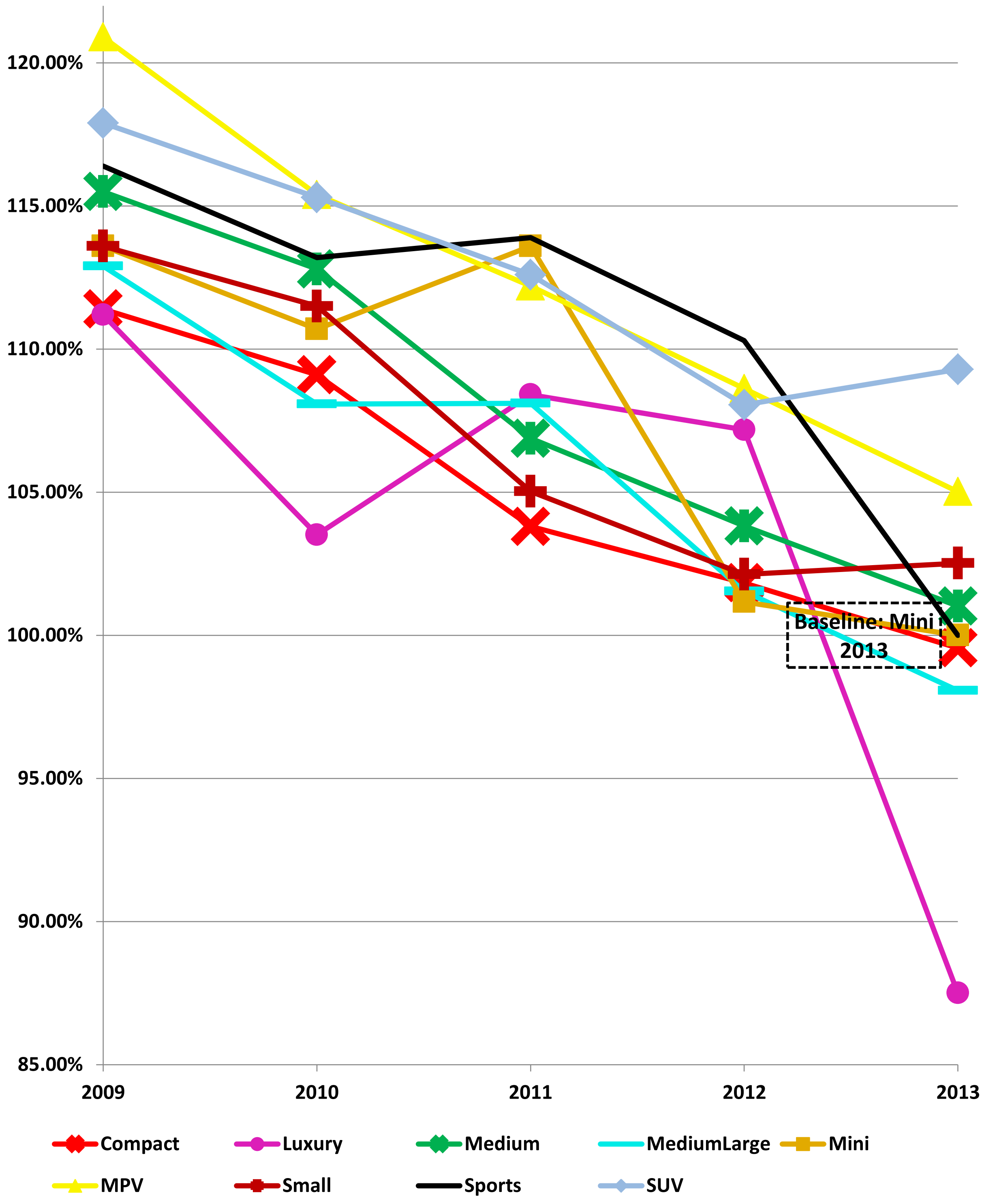


Figure 10 Country Effects: Level, No Grouping, Selected Countries

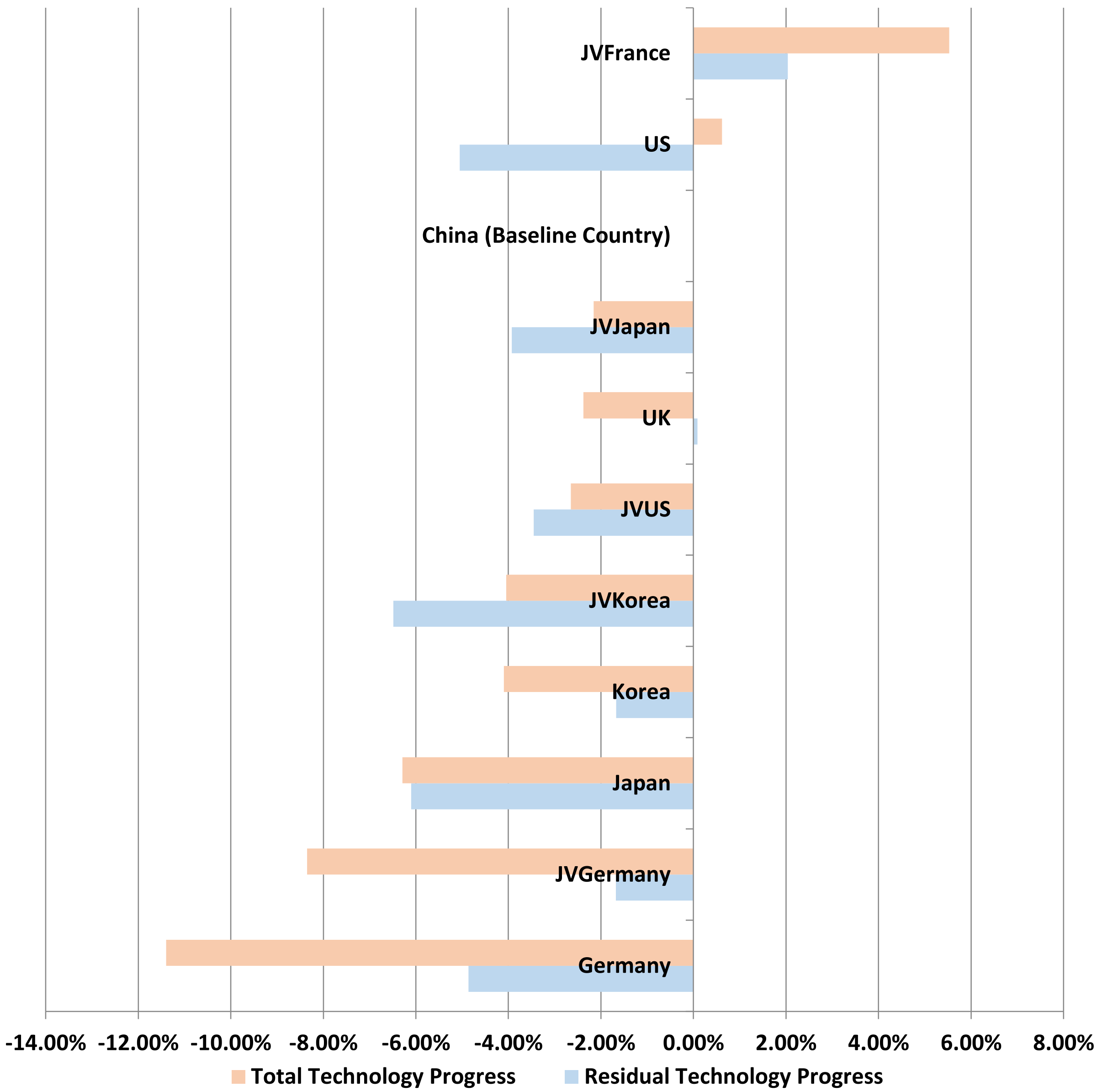


Figure 11 Country Effects: Level, with Grouping

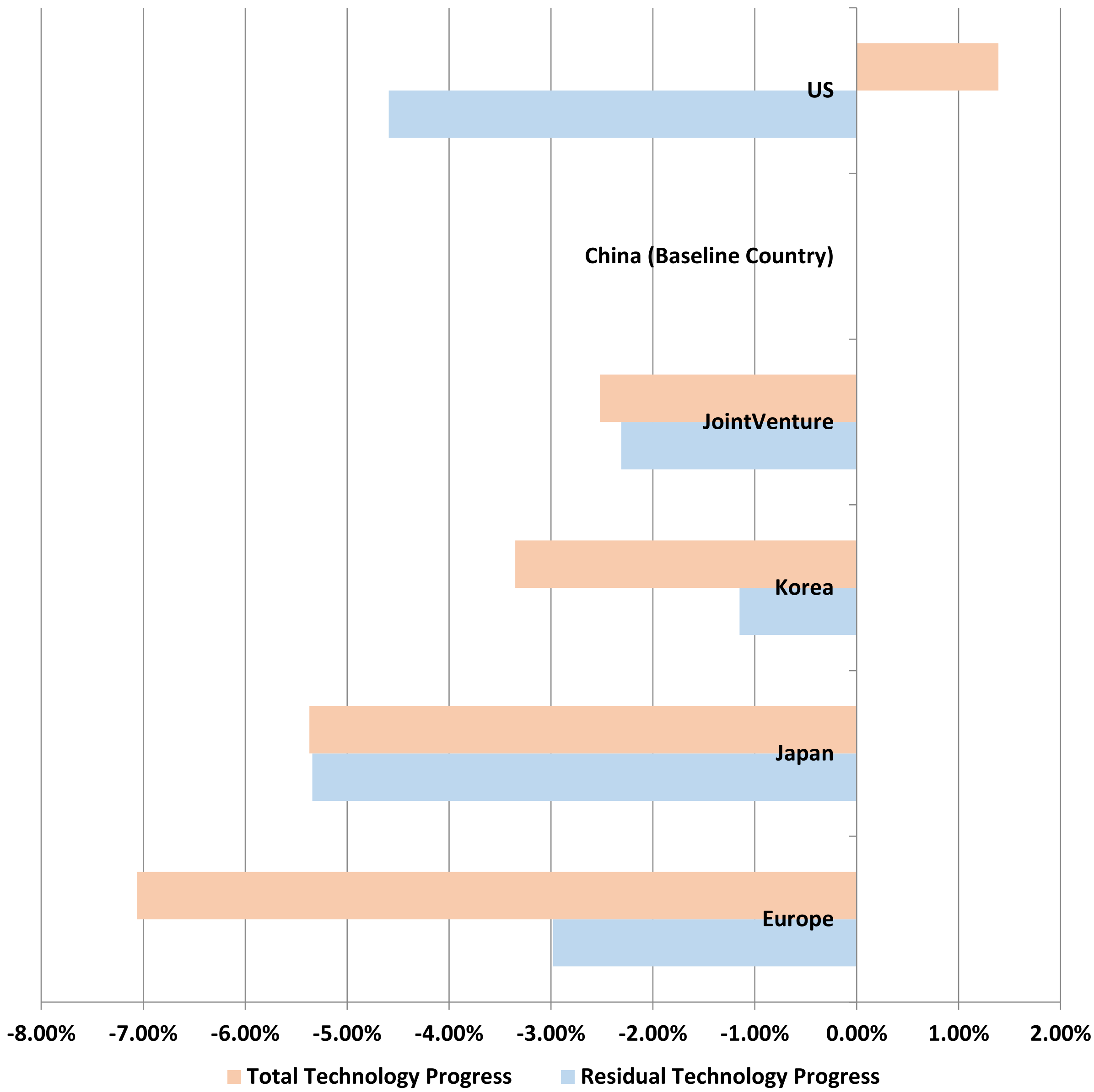


Figure 12 Country Effects: Linear Trend in Year, No Grouping, Selected Countries

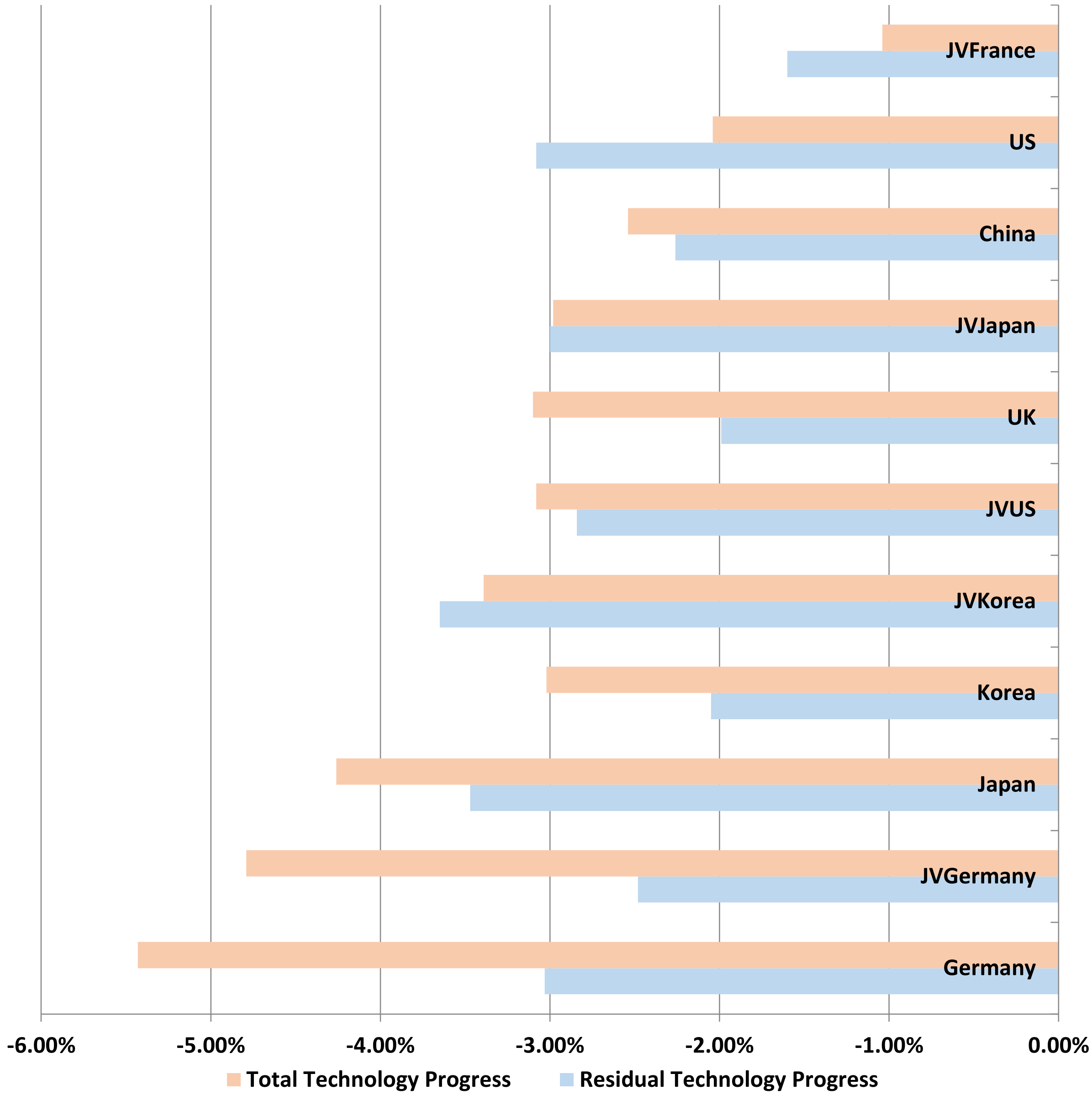


Figure 13 Country Effects: Linear Trend in Year, with Grouping

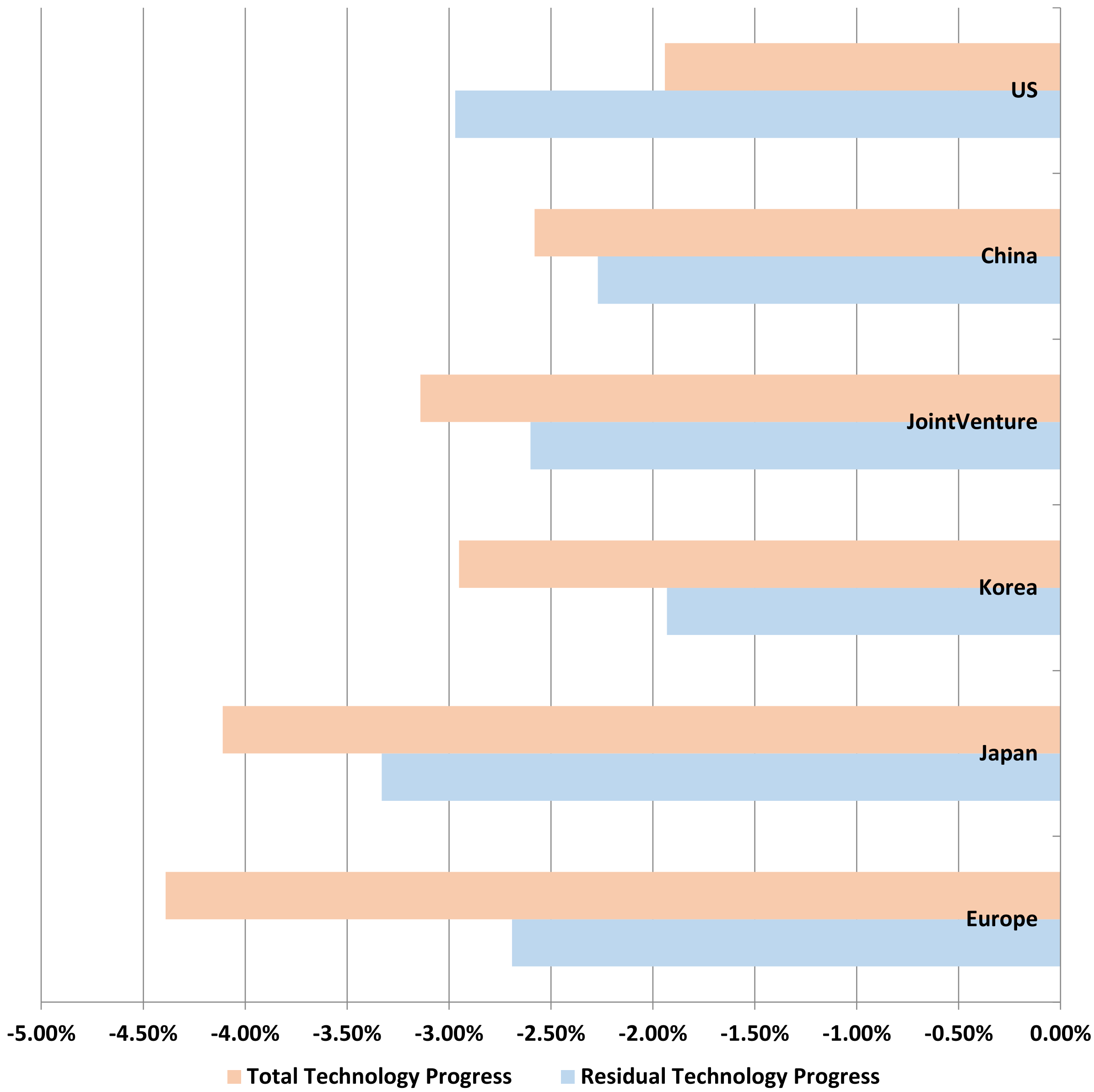


Figure 14 Manufacturer Effects: Level, No Grouping, 'Residual' Technology Progress, Selected Manufacturer

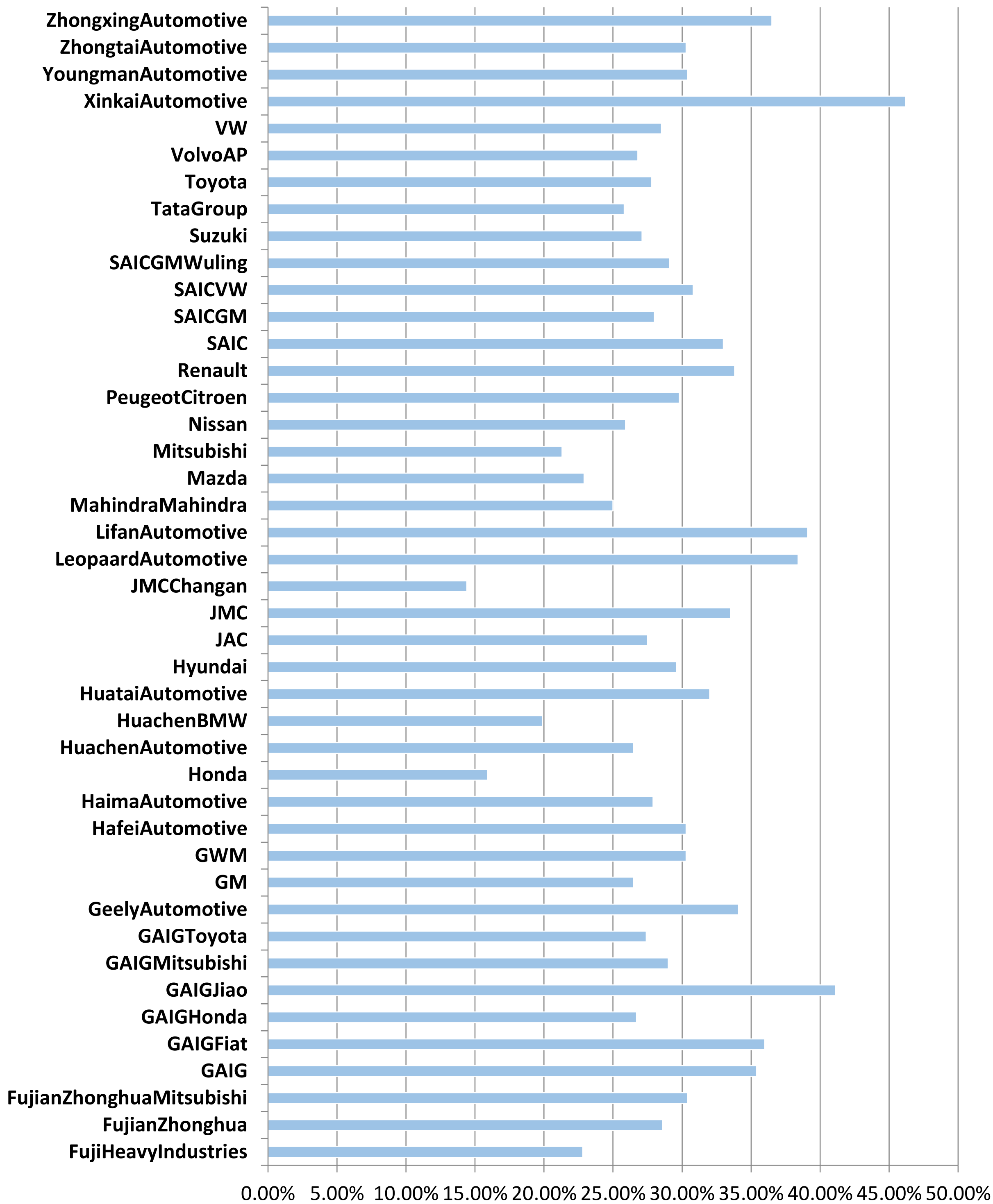


Figure 15 Manufacturer Effects: Level, No Grouping, 'Total' Technology Progress, Selected Manufacturer

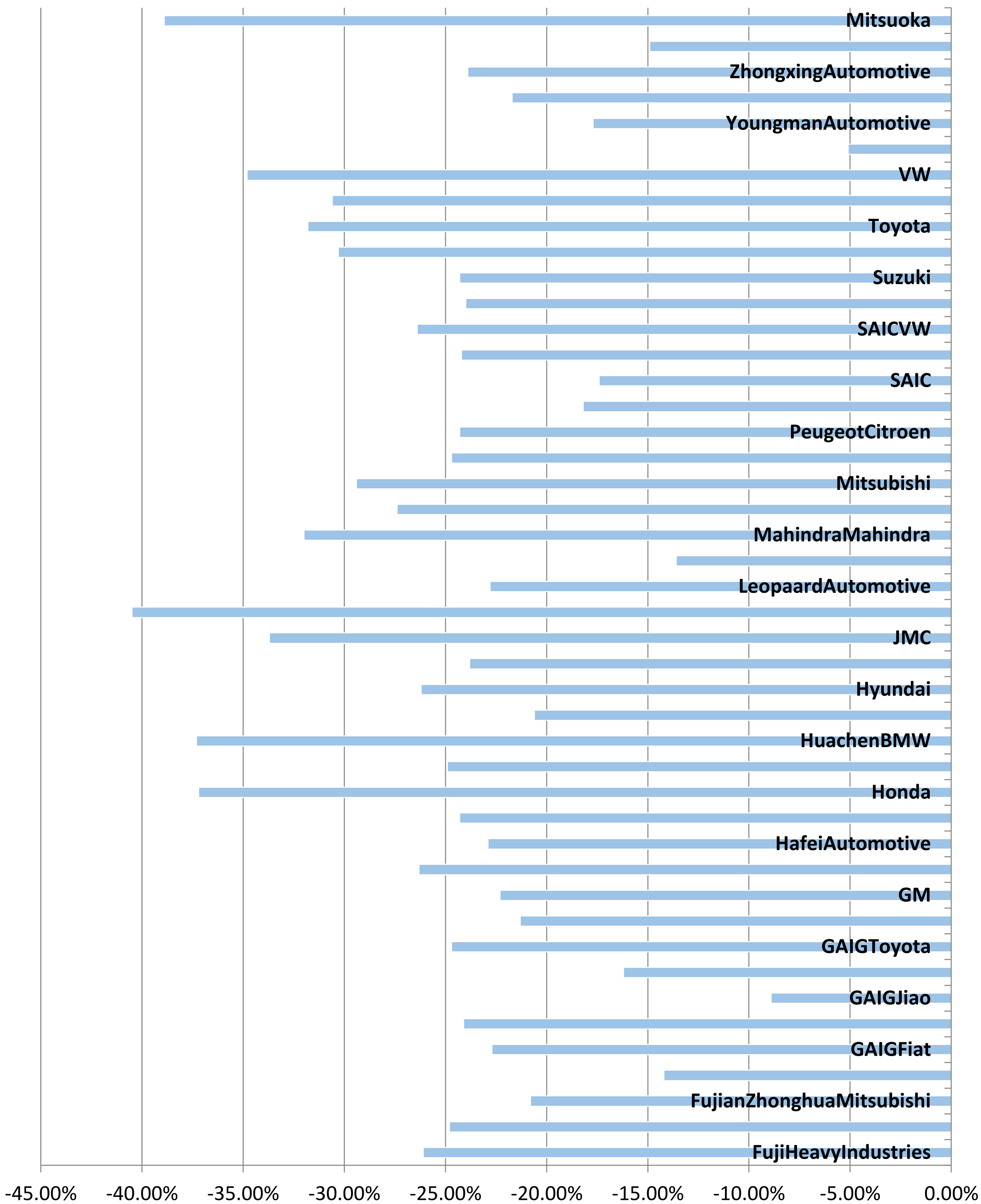


Figure 16 Sales-Weighted Fuel Consumption, Engine Power and Weight

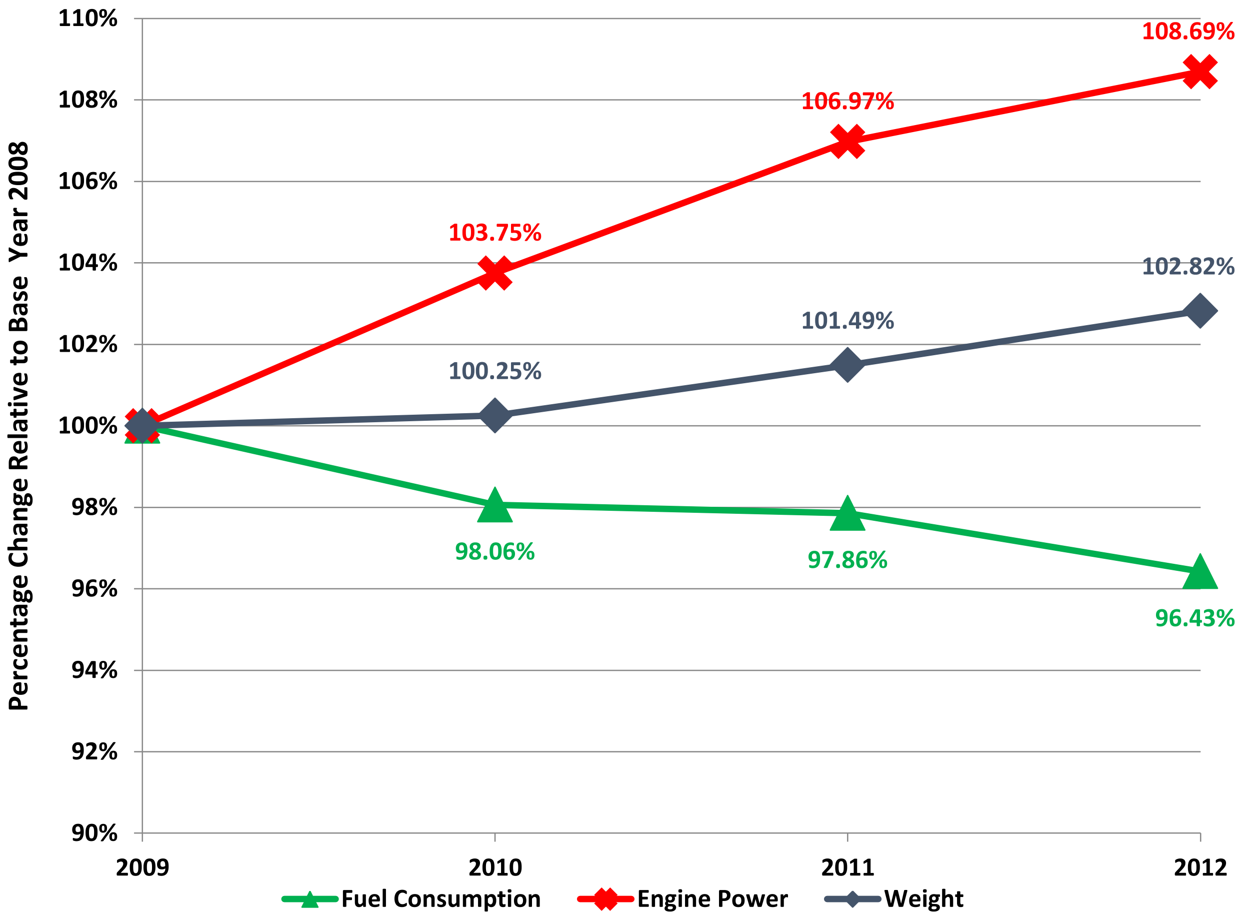


Figure 17 Baseline Model: 'Residual' Technology Progress and Actual Fuel Consumption

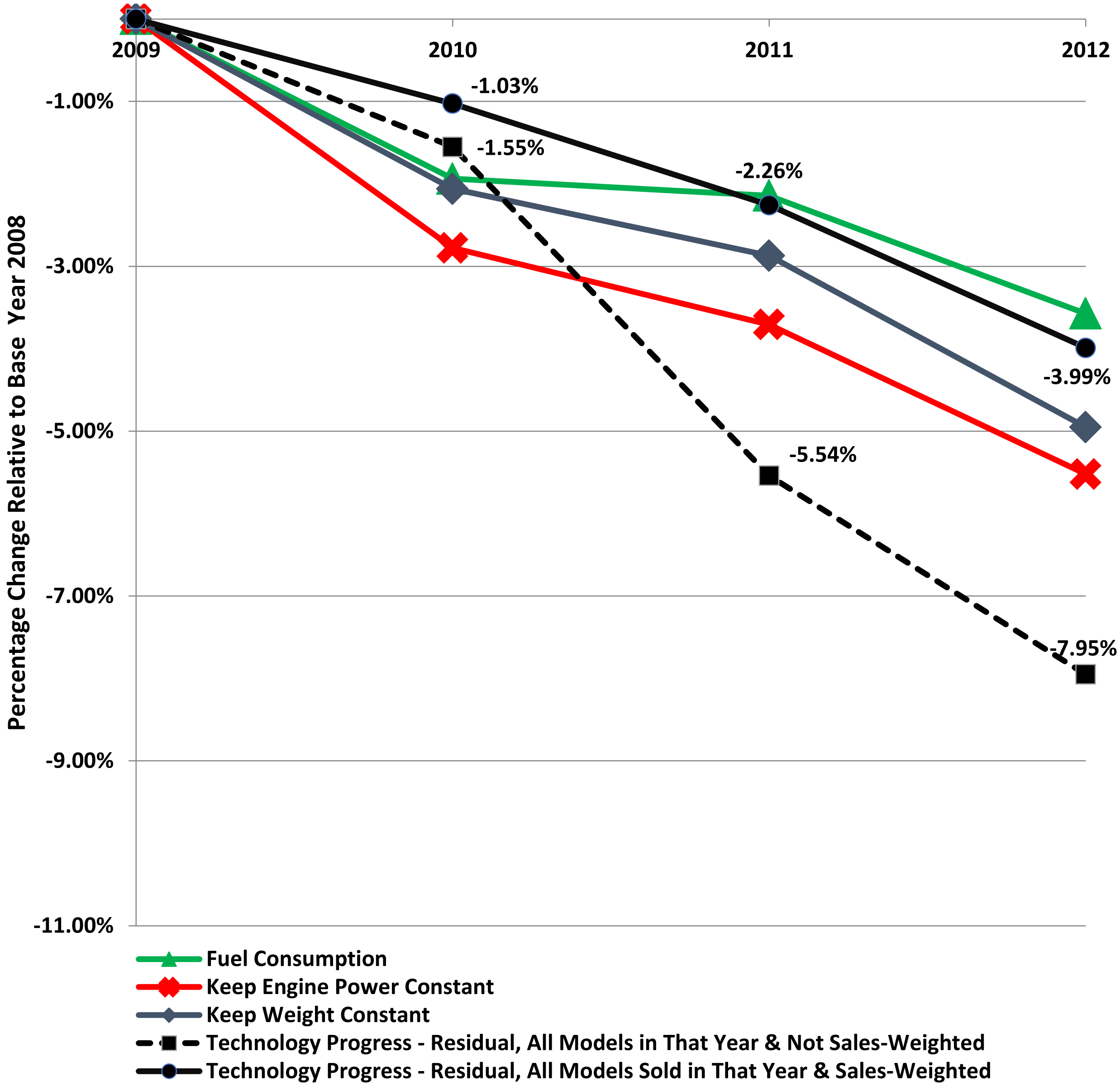


Figure 18 Baseline Model: 'Total' Technology Progress and Actual Fuel Consumption

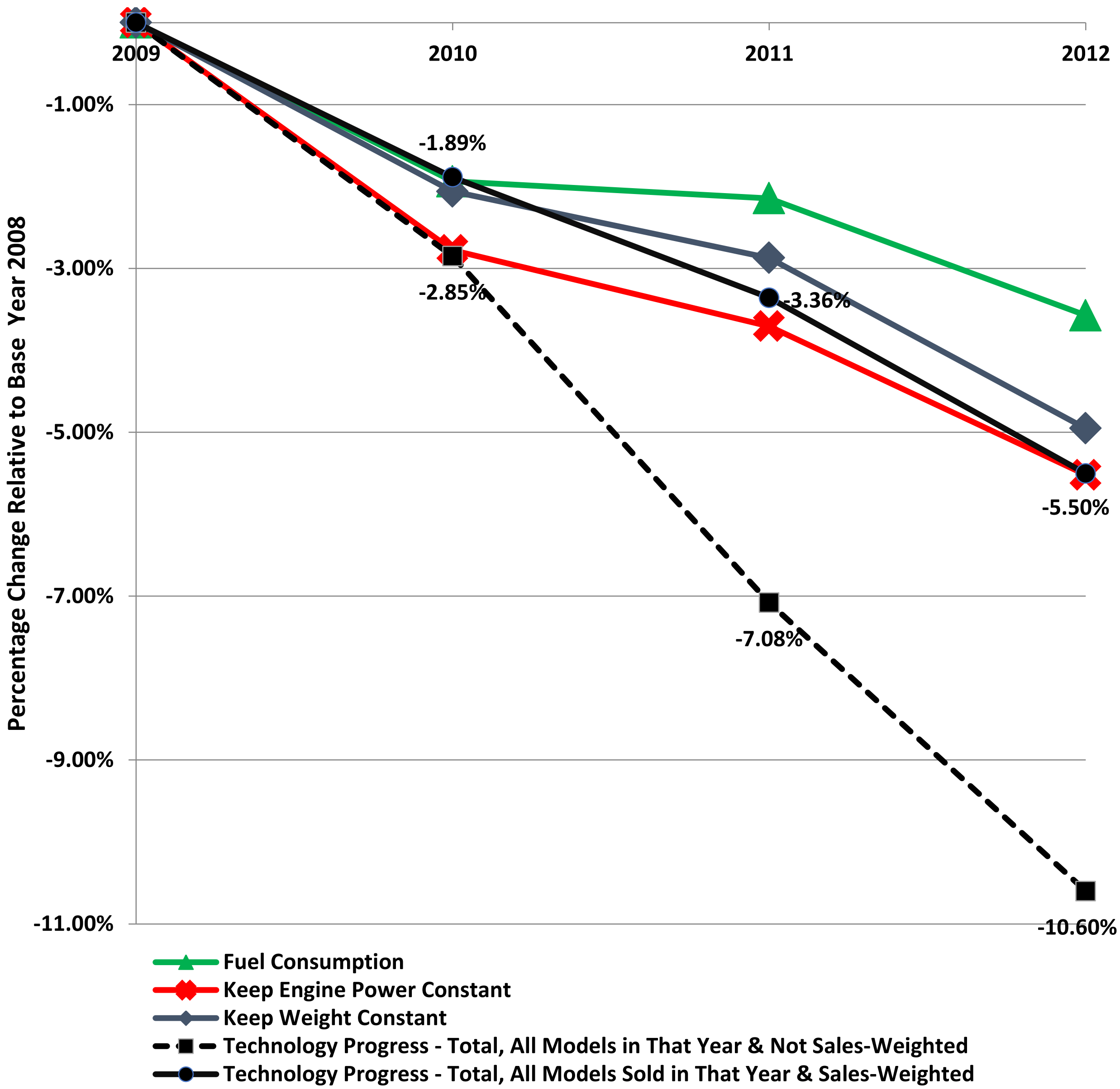


Figure 19 Segment Heterogeneity: 'Residual' Technology Progress and Actual Fuel Consumption

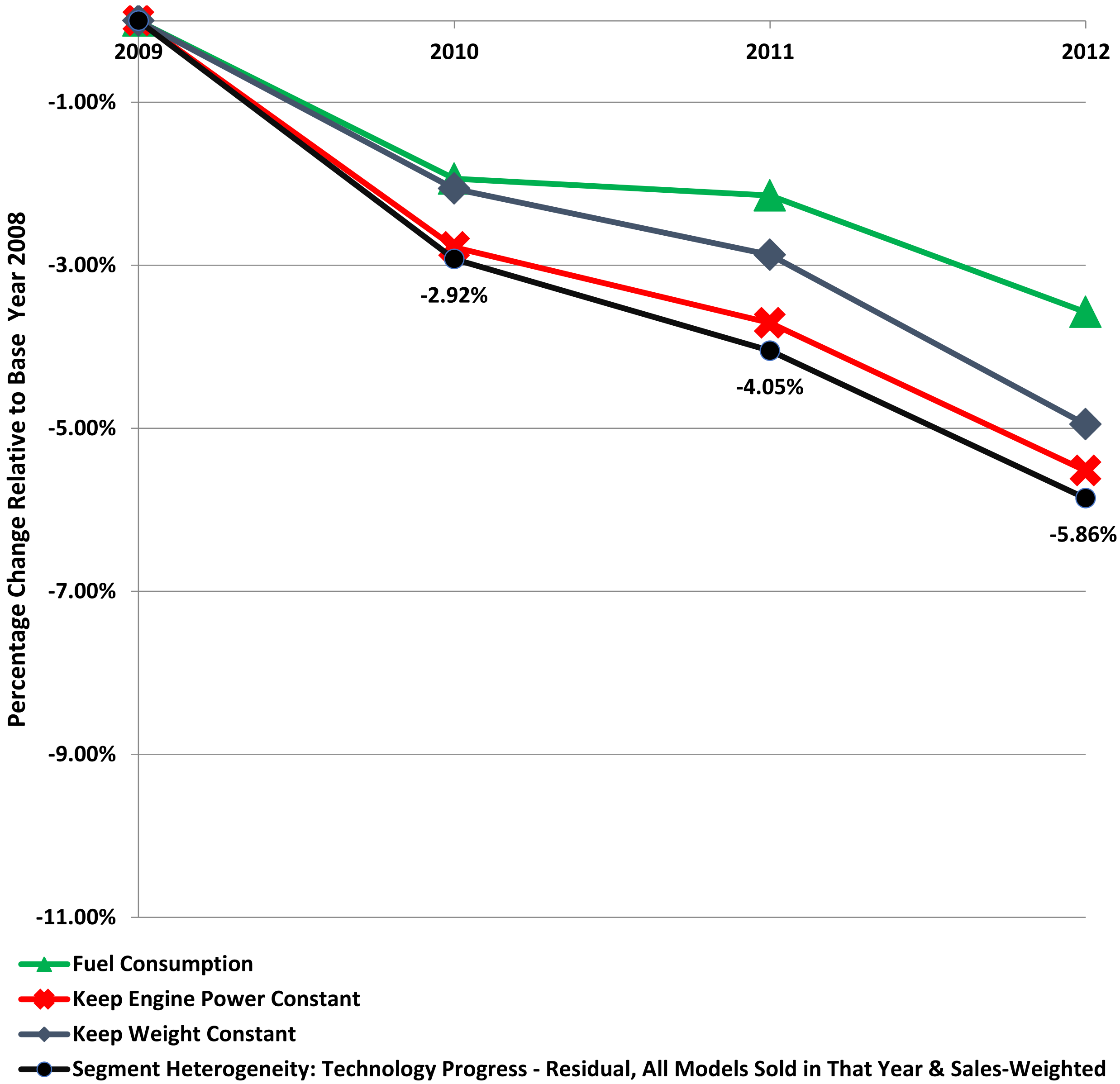
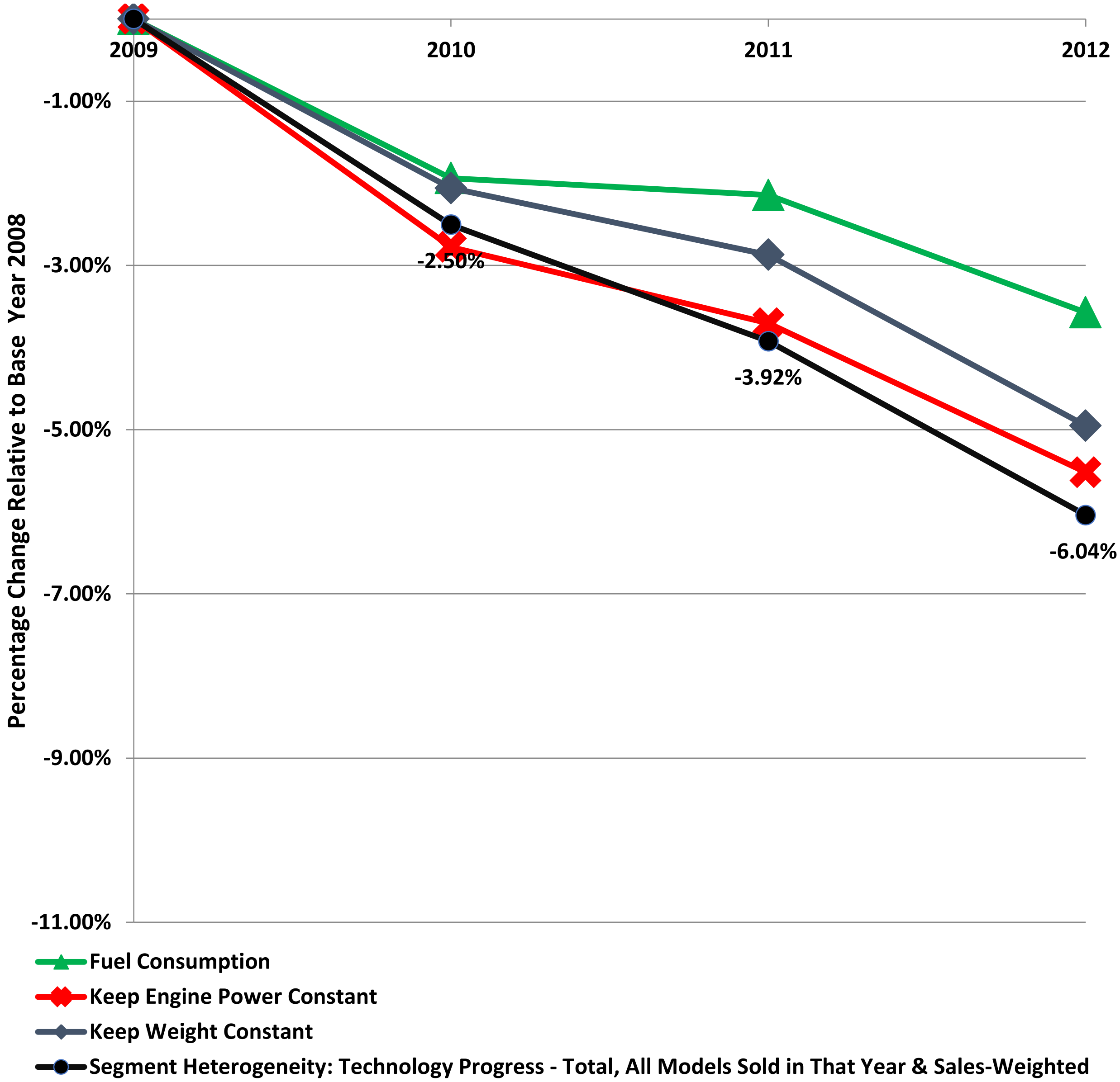


Figure 20 Segment Heterogeneity: 'Total' Technology Progress and Actual Fuel Consumption



APPENDIX

Table 1 Fuel Consumption Maximum Limits in Passenger Cars CAFE Standards Phase I & II

Unit: L/100km

Curb Weight (CM)/kg	Passenger Cars Phase I		Passenger Cars Phase II	
	Baseline Version	Special Structure (AT, ≥ 3 Rows or SUV)	Baseline Version	Special Structure (AT, ≥ 3 Rows or SUV)
CM ≤ 750	7.2	7.6	6.2	6.6
750 < CM ≤ 865	7.2	7.6	6.5	6.9
865 < CM ≤ 980	7.7	8.2	7.0	7.4
980 < CM ≤ 1,090	8.3	8.8	7.5	8.0
1,090 < CM ≤ 1,205	8.9	9.4	8.1	8.6
1,205 < CM ≤ 1,320	9.5	10.1	8.6	9.1
1,320 < CM ≤ 1,430	10.1	10.7	9.2	9.8
1,430 < CM ≤ 1,540	10.7	11.3	9.7	10.3
1,540 < CM ≤ 1,660	11.3	12.0	10.2	10.8
1,660 < CM ≤1,770	11.9	12.6	10.7	11.3
1,770 < CM ≤ 1,880	12.4	13.1	11.1	11.8
1,880 < CM ≤ 2,000	12.8	13.6	11.5	12.2
2,000 < CM ≤ 2,110	13.2	14.0	11.9	12.6
2,110 < CM ≤ 2,280	13.7	14.5	12.3	13.0
2,280 < CM ≤ 2,510	14.6	15.5	13.1	13.9
2,510 < CM	15.5	16.4	13.9	14.7

Table 2 Fuel Consumption Maximum Limits in LDCVs CAFE Standards Phase I & II

Unit: L/100km

Gross Vehicle Mass (GVM)/kg	Engine Displacement (ED)/L	LDCVs Phase I	LDCVs Phase II
N_1 vehicles Using Gasoline:			
GVM ≤ 2,000	All	8.0	7.8
2,000 < GVM ≤ 2,500	ED ≤ 1.5	9.0	8.1
	1.5 < ED ≤ 2.0	10.0	9.0
	2.0 < ED ≤ 2.5	11.5	10.4
	2.5 < ED	13.5	12.5
2,500 < GVM ≤ 3,000	ED ≤ 2.0	10.0	9.0
	2.0 < ED ≤ 2.5	12.0	10.8
	2.5 < ED	14.0	12.6
3,000 < GVM	ED ≤ 2.5	12.5	11.3
	2.5 < ED ≤ 3.0	14.0	12.6
	3.0 < ED	15.5	14.0
N_1 vehicles Using Diesel:			
GVM ≤ 2,000	All	7.6	7.0
2,000 < GVM ≤ 2,500	ED ≤ 2.5	8.4	8.0
	2.5 < ED ≤ 3.0	9.0	8.5
	3.0 < ED	10.0	9.5
2,500 < GVM ≤ 3,000	ED ≤ 2.5	9.5	9.0
	2.5 < ED ≤ 3.0	10.0	9.5
	3.0 < ED	11.0	10.5
3,000 < GVM	ED ≤ 2.5	10.5	10.0
	2.5 < ED ≤ 3.0	11.0	10.5
	3.0 < ED ≤ 4.0	11.6	11.0
	4.0 < ED	12.0	11.5
M_2 vehicles ≤ 3,500 kg Using Gasoline:			
GVM ≤ 3,000	ED ≤ 2.0	10.7	9.7
	2.0 < ED ≤ 2.5	12.2	11.0
	2.5 < ED ≤ 3.0	13.5	12.2
	3.0 < ED	14.5	13.1
3,000 < GVM	ED ≤ 2.5	12.5	11.3
	2.5 < ED ≤ 3.0	14.0	12.6
	3.0 < ED	15.5	14.0
M_2 vehicles ≤ 3,500 kg Using Diesel:			
GVM ≤ 3,000	ED ≤ 2.5	9.4	8.5
	2.5 < ED	10.5	9.5
3,000 < GVM	ED ≤ 3.0	11.5	10.5
	3.0 < ED	12.6	11.5

Table 3 Fuel Consumption Maximum Limits in HDCVs CAFE Standards Phase I

Unit: L/100km

Gross Vehicle Mass (GVM)/kg	HDCVs Phase I	
	Using Diesel	Using Gasoline
Goods Vehicles:		
3,500 < GVM ≤ 4,500	15.5	20.2
4,500 < GVM ≤ 5,500	16.5	21.5
5,500 < GVM ≤ 7,000	18.5	24.1
7,000 < GVM ≤ 8,500	22.0	28.6
8,500 < GVM ≤ 10,500	24.0	31.2
10,500 < GVM ≤ 12,500	28.0	36.4
12,500 < GVM ≤ 16,000	31.0	40.3
16,000 < GVM ≤ 20,000	35.0	45.5
20,000 < GVM ≤25,000	41.0	53.3
25,000 < GVM ≤ 31,000	47.5	61.8
31,000 < GVM	50.0	65.0
Semi-Trailer Towing Vehicles:		
GVM ≤ 18,000	38.0	
18,000 < GVM ≤ 27,000	42.0	
27,000 < GVM ≤ 35,000	45.0	
35,000 < GVM ≤ 40,000	47.0	
40,000 < GVM ≤ 43,000	49.0	
43,000 < GVM ≤ 46,000	51.5	
46,000 < GVM ≤ 49,000	54.0	
49,000 < GVM	56.0	
Buses:		
3,500 < GVM ≤ 4,500	14.0	18.2
4,500 < GVM ≤ 5,500	15.5	20.2
5,500 < GVM ≤ 7,000	17.0	22.1
7,000 < GVM ≤ 8,500	19.0	24.7
8,500 < GVM ≤ 10,500	21.0	27.3
10,500 < GVM ≤ 12,500	22.5	29.3
12,500 < GVM ≤ 14,500	23.5	30.6
14,500 < GVM ≤ 16,500	25.0	32.5
16,500 < GVM ≤18,000	26.0	33.8
18,000 < GVM ≤ 22,000	27.5	35.8
22,000 < GVM ≤ 25,000	30.0	39.0
25,000 < GVM	33.0	42.9

Table 4 Fuel Consumption Maximum Limits in Passenger Cars CAFE Standards Phase III

Unit: L/100km

Curb Weight (CM)/kg	Passenger Cars Phase III	
	Baseline Version	Special Structure (AT or ≥ 3 Rows)
CM ≤ 750	5.2	5.6
750 < CM ≤ 865	5.5	5.9
865 < CM ≤ 980	5.8	6.2
980 < CM ≤ 1,090	6.1	6.5
1,090 < CM ≤ 1,205	6.5	6.8
1,205 < CM ≤ 1,320	6.9	7.2
1,320 < CM ≤ 1,430	7.3	7.6
1,430 < CM ≤ 1,540	7.7	8.0
1,540 < CM ≤ 1,660	8.1	8.4
1,660 < CM ≤1,770	8.5	8.8
1,770 < CM ≤ 1,880	8.9	9.2
1,880 < CM ≤ 2,000	9.3	9.6
2,000 < CM ≤ 2,110	9.7	10.1
2,110 < CM ≤ 2,280	10.1	10.6
2,280 < CM ≤ 2,510	10.8	11.2
2,510 < CM	11.5	11.9

Table 5 Matching between Brands, Countries and Manufacturers

Brand	Country	Manufacturer
Acura	Japan	Honda
Alfa Romeo	Italy	Fiat
Aston Martin	UK	Aston Martin
Audi	Germany	VW
Audi RS	Germany	VW
BAIC	China	BAIC
BAIC Weiwang	China	BAIC
Baojun	JVChina	SAIC-GM-Wuling
BAW	China	BAIC
Beijing Benz	JVGermany	Beijing Benz
Beijing Hyundai	JVKorea	Beijing Hyundai
Bentley	UK	VW
Benz	Germany	Daimler AG
Benz AMG	Germany	Daimler AG
Besturn	China	FAW
BMW	Germany	BMW
BMW M	Germany	BMW
Brabus	Germany	Brabus
Bugatti	France	VW
Buick	US	GM
BYD	China	BYD
Cadillac	US	GM
Carlsson	Germany	Carlsson
Chang'an CV	China	Chang'an
Chang'an Ford	JVUS	Chang'an Ford
Chang'an Mazda	JVJapan	Chang'an Mazda
Chang'an Peugeot Citroën DS	JVFrance	Chang'an Peugeot-Citroen
Chang'an PV	China	Chang'an
Chang'an Suzuki	JVJapan	Chang'an Suzuki
Chang'an Volvo	JVSweden	Chang'an Volvo
Changhe	China	Changhe Automotive
Changhe Suzuki	JVJapan	Changhe Suzuki
Chery	China	Chery Automotive
Chevorlet	US	GM
Chrysler	US	Chrysler
Chuangqi Yema	China	Chuanqi Group
Citroën	France	Peugeot Citroen
DFMC	China	DFMC
DFMC Citroën	JVFrance	DFMC Peugeot-Citroen

DFMC Fengshen	China	DFMC
DFMC Fengxing	China	DFMC
DFMC Honda	JVJapan	DFMC Honda
DFMC Honda Ciimo	JVChina	DFMC Honda
DFMC Nissan	JVJapan	DFMC Nissan
DFMC Nissan Venucia	JVChina	DFMC Nissan
DFMC Peugeot	JVFrance	DFMC Peugeot-Citroen
DFMC Xiaokang	China	DFMC Xiaokang
DFMC Zhengzhou Nissan	JVJapan	DFMC Nissan
DFMC-Yueda-Kia	JVKorea	DFMC-Yueda-Hyundai
Dodge	US	Chrysler
DS	France	Peugeot Citroen
FAW GM	JVUS	FAW GM
FAW Hongqi	China	FAW
FAW Jilin	China	FAW
FAW Mazda	JVJapan	FAW Mazda
FAW Oulang	China	FAW
FAW Toyota	JVJapan	FAW Toyota
FAW VW	JVGermany	FAW VW
FAW VW Audi	JVGermany	FAW VW
Ferrari	Italy	Fiat
Fiat	Italy	Fiat
Ford	US	Ford
Foton	China	BAIC
Fudi	China	Fudi Automotive
Fujian Benz	JVGermany	Fujian-Zhonghua-Daimler
GAIG Fiat	JVItaly	GAIG Fiat
GAIG Honda	JVJapan	GAIG Honda
GAIG Honda Everus	JVChina	GAIG Honda
GAIG Ji'ao	China	GAIG Ji'ao
GAIG Mitsubishi	JVJapan	GAIG Mitsubishi
GAIG PV	China	GAIG
GAIG Toyota	JVJapan	GAIG Toyota
Geely Eagle	China	Geely Automotive
Geely Emgrand	China	Geely Automotive
Geely Englon	China	Geely Automotive
GMC	US	GM
Golden Dragon	China	Golden Dragon
Great Wall	China	GWM
Hafei	China	Hafei Automotive
Haima	China	Haima Automotive
Haima Zhengzhou	China	Haima Automotive
Haval	China	GWM

Hengtian	China	Hengtian Automotive
Higer	China	Golden Dragon
Honda	Japan	Honda
Huachen BMW	JVGermany	Huachen BMW
Huachen Jinbei	China	Huachen Automotive
Huachen Zhonghua	China	Huachen Automotive
Huanghai	China	Shuguang Automotive
Huatai	China	Huatai Automotive
Hummer	US	GM
Hyundai	Korea	Hyundai
Infiniti	Japan	Nissan
JAC	China	JAC
Jaguar	UK	Tata Group
Jeep	US	Chrysler
JMC	China	JMC
JMC Ford	JVUS	JMC Ford
John Cooper Works	Germany	BMW
Jonway	China	Jonway Automotive
Joylong	China	Joylong Automotive
Karry	China	Chery Automotive
Kia	Korea	Hyundai
Koenigsegg	Sweden	Koenigsegg
Lamborghini	Italy	VW
Landrover	UK	Tata Group
Landwind	China	JMC Chang'an
Leopaard	China	Leopaard Automotive
Lexus	Japan	Toyota
Lifan	China	Lifan Automotive
Lincoln	US	Ford
Lorinser	Germany	Daimler AG
Lotus	UK	Lotus
Luxgen	JVTaiwan	DFMC Yulon
Maserati	Italy	Fiat
Maybach	Germany	Daimler AG
Mazda	Japan	Mazda
McLaren	UK	McLaren Group
MG	UK	SAIC
MINI	Germany	BMW
Mitsubishi	Japan	Mitsubishi
Mitsuoka	Japan	Mitsuoka
Morgan	UK	Morgan Motor Company
Nanjing IVECO	JVItaly	SAIC Fiat
Nissan	Japan	Nissan

Opel	Germany	GM
Oullim Motors	Korea	Oullim Motors
Peugeot	France	Peugeot Citroen
Porsche	Germany	VW
Qingling	JVJapan	Qingling Automotive
Rely	China	Chery Automotive
Renault	France	Renault
Riich	China	Chery Automotive
Rolls-Royce	UK	BMW
RUG	Germany	RUF
Saab	Sweden	GM
SAIC CV	China	SAIC
SAIC GM Buick	JVUS	SAIC GM
SAIC GM Cadillac	JVUS	SAIC GM
SAIC GM Chevorlet	JVUS	SAIC GM
SAIC GM Wuling	JVUS	SAIC-GM-Wuling
SAIC Roewe	China	SAIC
SAIC VW	JVGermany	SAIC VW
SAIC VW Škoda	JVCzech Republic	SAIC VW
Seat	Spain	VW
Shanghai Huizhong	China	SAIC
Shanghai Maple	China	Geely Automotive
Shanqi Tongjia	China	Shanqi Group
Shenbao	China	BAIC
Shuanghuan	China	Shuanghuan Automotive
Škoda	Czech Republic	VW
smart	Germany	Daimler AG
Southeast	JVTaiwan	Fujian-Zhonghua
Southeast Chrysler	JVUS	Fujian-Zhonghua-Chrysler
Southeast Mitsubishi	JVJapan	Fujian-Zhonghua-Mitsubishi
Spyker	Netherlands	Spyker
SsangYong	Korea	Mahindra & Mahindra
Subaru	Japan	Fuji Heavy Industries
Suzuki	Japan	Suzuki
Tesla	US	Tesla
Tianjin FAW	China	FAW
Toyota	Japan	Toyota
Volvo	Sweden	Geely Automotive
Volvo Asia Pacific	JVSweden	Volvo AP
VW	Germany	VW
Wiesmann	Germany	Wiesmann
Xiamen Jinlv	China	Golden Dragon
Xinkai	China	Xinkai Automotive

Youngman Lotus	JVUK	Youngman Automotive
Zhengzhou Nissan	JVJapan	FAW Nissan
Zhongtai	China	Zhongtai Automotive
Zhongxing	China	Zhongxing Automotive

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