Incentives to Invest in New Technology:

The Effect of Fuel Economy Standards on China's Automakers

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Abstract

Technology absorption is critical to emerging market growth. To study this process I exploit fuel economy standards, which compel automakers to either acquire fuel efficiency technology or reduce vehicle quality. With novel, unique data on the Chinese auto market between 1999 and 2012, I evaluate the effect of China's 2009 fuel economy standards on firms' vehicle characteristic choices. Through differences-in-differences and triple differences designs, I show that Chinese firms responded to the new policy by manufacturing less powerful, cheaper, and lighter vehicles. Foreign firms manufacturing for the Chinese market, conversely, continued on their prior path. For example, domestic firms reduced model torque and price by 12% and 13% of their respective means relative to foreign firms. Private Chinese firms outperformed state-owned firms and were less affected by the standards, but Chinese firms in joint ventures with foreign firms suffered the largest negative effect regardless of ownership. My evidence suggests that fuel economy standards and joint venture mandates - both *intended* to increase technology transfer - have instead retarded Chinese firms' advancement up the automotive manufacturing quality ladder.

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JEL classifications: G3, O2, O3, P2, P3, Q4, Q5, L5, L9

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"We have been trying to exchange market access for technology, but we have barely gotten hold of any key technologies in the past 30 years"

- Liao Xionghui, Vice President of Lifan, a Chinese automaker (Ying 2012)

"New proposed fuel-economy standards for passenger cars...[leave] foreign makers well positioned to inject new technology...That leaves locals such as Great Wall and Geely with the most work to do."

- Bhattacharya (Wall Street Journal, 2014)

1 Introduction

Despite 35 years of industrial policy targeting a globally competitive, high quality indigenous auto sector, domestic Chinese automakers have not acquired the technology necessary to compete with foreign automakers. Foreign brands dominate China's passenger vehicle market - the world's largest since 2010 - by quality, price, and market share.[1] Chinese exports are minimal, and near zero to the developed world. Not only are quality and exports associated with higher profit margins in automotive manufacturing, but domestic firms' decision to produce low quality, low price vehicles runs counter to explicit government directives. Further, domestic firms' lagging technological capacity contrasts with other high-tech sectors, where Chinese firms, some majority state-owned, produce and export at globally competitive quality levels. It also contrasts with the rapid progress achieved by Japanese and Korean automakers in the 1970s and 1980s.[2]

Why did Chinese automakers choose to make small, cheap, low quality cars instead of investing in the power-train, safety, and design technology needed to compete in higher value segments? In this paper I propose two hypotheses: 1) the sudden imposition of fuel economy standards increased the barrier to entry in high quality segments; and 2) the joint venture mandate for foreign entry disincentivized technology upgrading. Both were enabled by high tariffs that precluded imports.

High quality vehicles have greater torque (acceleration) and horsepower. They have more accessories like air conditioning, and are usually bigger and heavier, and thus safer.[3] There is a basic tradeoff between these characteristics and fuel economy. An automaker

[1] For cross-country market size comparisons, see Wang et al. (2013).

[2] See Appendix B for a comparison of the auto sector with other sectors in China and with auto sectors in other countries.

[3] The relationship between weight and safety is well-documented. See, for example, Anderson and Auffhammer (2014) and Consumer Guide Automotive (2014).

faced with fuel economy standards can either reduce quality to meet the standard or invest in developing or acquiring fuel efficiency technologies. China's sudden and stringent fuel economy standards aimed to hasten technology transfer. Yet they imposed fixed costs of technology acquisition on domestic firms. Foreign firms, who already faced high standards in other markets, incurred only the variable cost of including their technologies in Chinese production. A fixed cost disadvantage may have pushed domestic firms to produce lighter, smaller, and cheaper cars to meet the standard without investing in new fuel efficiency technologies.

I use detailed, novel data on model-level sales and characteristics between 1999 and 2012.[4] I assess the fuel economy standards' effect on model characteristic decisions of domestic Chinese automakers. My primary approach compares foreign to domestic branded vehicles before and after the policy, in a differences-in-differences design. I find that domestic Chinese firms responded to the 2009 fuel economy standards by reducing their models' torque, horsepower, weight, and price.[5] I find weak evidence that they also reduced vehicle height and length. Foreign model characteristics continued on their pre-policy trajectory.

Specifically, I find that the standards reduced vehicle torque in domestic models relative to foreign models by 17 nm, or about 11.5% of mean torque among domestic firms, and horsepower by 6.3 kw, or 8% of the mean. The standards reduced domestic model price by \$2,784 (13% of the mean), weight by 55 kg (4.3% of the mean), and length by 91 m (2.1% of the mean), all relative to foreign models. The policy's effect on all characteristics grows when I restrict the sample to models with larger sales volume. In my primary specification, I pool data on both sides of the policy and cluster standard errors by group (firm) to reduce bias from serial correlation of the variables. I also include firm fixed effects. I conduct a rich array of robustness tests, including placebo with other years, different bandwidths around the policy, different types of fixed effects, and alternative assumptions about standard errors.

A second empirical approach exploits the standards' staged implementation for new models in 2008, and continuing models in 2009. For example, the 2009 Great Wall Peri was a new model as it was not produced in 2008, while the 2009 Volkswagen Jetta was a continuing model. A triple differences design reveals that in 2008, domestic firms' continuing models (not yet subject to the policy) were more powerful, more expensive, larger, and heavier than new models. As with the differences-in-differences design, the primary triple differences

[4]The sales data are from the State Council Development Research Center in Beijing, and are linked to model-year characteristics collected from the internet. I also have data from 2013, which will be incorporated in a future version.

[5]China imposed fuel economy standards in phases from 2005-2009, but the more stringent binding standards only came into force in 2009 (See Section 2.2).

specification examines within-firm variation, netting out the foreign-domestic firm and 2008-2007 differences.

My results establish that the fuel economy policy failed to achieve its original motivation of forcing increased technology transfer. From a social welfare perspective, although China's fleet became more fuel efficient, it also became more unsafe. An increasing share of vehicles are either very heavy or very light, making crashes more likely fatal, and poor quality in Chinese vehicles is accompanied by reduced safety (see Sections 2.2 and 6.2). From a private welfare perspective, Chinese firms may maximize profits by producing at the bottom end of the quality-price distribution. Yet the absence of Chinese exports despite explicit government export targets, evidence from the global market that exports are positively associated with profits, and the failure of Chinese firms to gain market share together suggest that thus far the down-market strategy has not been successful.

However, China's automotive industry is changing rapidly. New organizational structures, including independent engineering and design firms that allow domestic automakers to outsource R&D, may allow Chinese firms in the future to undercut foreign competition for small, cheap cars in China and elsewhere (Shirouzu 2012). The results in this paper apply only to the industry through 2012.

I explore the mechanism driving Chinese firms' poor quality outcomes by comparing the performance of firms along two dimensions: whether the firm has a JV with a foreign firm, and whether it is privately owned or is a state-owned enterprise (SOE) at the central or local level. All foreign firms that manufacture vehicles in China do so through JVs, enterprises that produce foreign branded vehicles (such as the Mazda 6) but that pass about 50% of profits to a Chinese partner (in Mazda's case, FAW Auto), which produces domestic brand vehicles in separate plants. In theory, the domestic partner has greater access to the foreign firm's R&D and manufacturing capabilities than it would without a JV, and thus a lower cost of technology absorption. The popular press and some political science literature has argued, however, that the JV policy failed to spur technology transfer (e.g. Thun 2004).

Is there an "innovation cost" to FDI through JVs? This is an important policy question in many developing economies whose industrial policy has required FDI through JVs (e.g. Mathews 2002). China leveraged its bargaining power - access to the domestic market - to mandate JVs. On one hand, Chinese firms extracted large rents and the JVs created many jobs, some high skill. Yet dynamically the industry structure may have reduced domestic firm innovation incentives. In a stylized model, I show how domestic firms with JVs could be disincentivized from producing substitutes to their foreign partners' models to avoid cannibalizing their share of foreign brand profits. That is, the negative effect of increasing own quality on the share of JV profits might outweigh the JV's technology acquisition cost advantage.

I evaluate the effect of the fuel economy policy on subsets of firms, and show that SOEs with JVs were primarily responsible for the negative effects of the policy on domestic firm quality and price. Private firms without JVs responded least to the policy, and private firms also generally outperformed SOEs over the whole period. This is consistent with previous literature documenting greater productivity of private firms in China (e.g. Khandelwal et al. 2012, Lin et al. 1998). However, the negative effect of having a JV appears stronger than the negative effect of being state-owned. This suggests that requiring JVs in order to accelerate technology transfer may be misguided.

Technology diffusion is central to economic development (Lucas 1993, Young 1991, Nelson and Phelps 1966). In particular, increasing the quality of manufactures is often assumed necessary for export success and growth (Kremer 1993, Grossman and Helpman 1991a). Guided by the empirical fact that successful emerging markets in the post-WWII period developed innovation capacity by first obtaining foreign technology, the literature typically posits that growth depends on the rate of technology adoption (Parente and Prescott 1994, Grossman and Helpman 1991b). When and at what rate firms learn helps explain income disparities across countries, and is pivotal to the effectiveness of infant industry protection. However, the evidence about these policies is mixed; in particular, FDI's role in technology diffusion and growth is contested in both research and policy (Blalock and Gertler 2007, Hale and Long 2012).

Acquiring technology is costly, whether by own development, licensing, JVs, M&A, imitation, or theft. This is especially true in the modern automotive industry, where technology absorption involves considerable tacit knowledge in engineering, manufacturing, and other types of human capital (Ahrens 2013). I present evidence that a set of distortionary policies designed to protect (high tariffs), nurture (JVs), and prod (fuel economy standards) an infant industry backfired.

My analysis departs from much of the past literature by focusing on the technical quality of firm products, rather than accounting-based measures of productivity like labor cost. Though my findings are limited to a specific sector, country, and time period, the question of how government policy affects incentives to invest in technology upgrading is broadly applicable. This paper contributes to the literatures on industrial policy, technology transfer, the Chinese economy, and the impacts of energy efficiency regulation. I show that standards based on weight and vehicle type perversely incentivize automakers to produce more SUVs, which relates to the literature on the counterproductive effects of attribute-based regulations, such as the U.S. Energy Star program for household appliances (Aldy and Houde 2015).

In Section 2, I provide historical context about the Chinese auto sector and explain the fuel economy standards. I present the data and provide descriptive statistics in Section 3. I propose the estimation strategy in Section 4. Section 5 contains the main results and robustness tests. In Section 6, I analyze the role of JVs and SOEs in the auto sector, and assess their relative response to the fuel economy standards. Section 7 concludes.

2 China's Auto Industry Structure and Fuel Economy Standards

2.1 China's Auto Sector in Historical Context

Chinese policymakers considered light-duty passenger vehicles to be inessential luxury goods until the "Opening and Reform" of 1978. Indeed, before 1984 personal vehicle ownership was technically illegal (Anderson 2012). But in 1986, the central government designated the automotive sector a "Pillar Industry," and it has subsequently described automobile production as key to China's development.[6] Even the most recent automotive sector plan states that "Development of the automobile industry, including transformational upgrading, is an urgent task and is important for new economic growth and international competitive advantage" (State Council 2012).

From the early 1980's, the central government's auto policy focused on inducing technology transfer from foreign to domestic firms, primarily through encouraging foreign direct investment (FDI) (e.g. State Council 2006). Initially widely perceived as an avenue to knowledge spillovers, the role of FDI in technology diffusion is now contested in the empirical literature.[7] In practice, many countries subsidize FDI while others restrict it, and some

[6]The 7th Five-Year Plan issued in 1986 instructed policymakers to consider the "automotive industry as an important pillar industry, and it should follow the principles of 'high starting point, mass production, and specialization' to establish backbone enterprises as leaders." See Chu (2011)

[7]Borensztein et al. (1998) find in a large sample of countries that FDI has larger positive effect on growth than domestic investment. Similarly, Xu (2008) finds that FDI positively impacts innovation (patenting) in China, and Haskel et al. (2007) find a positive effect of FDI on TFP in the UK. Blalock and Gertler (2007) find strong evidence that foreign investment generates Pareto improving technology transfer, increasing productivity, profits and output in the local market. Other work, such as Haddad and Harrison (1993), Konings (2001), and Aitken and Harrison (1999) find negative effects of FDI on productivity in Morocco, Eastern Europe, and Venezuela, respectively. See Hale and Long (2011 and 2012) for a review

switch between the two (UNCTAD 2012). China allowed foreign firms to manufacture light duty vehicles in China *only* in partnerships with domestic firms; the idea was to exchange market access for foreign technology. The JV is a stand-alone enterprise no more than 50% owned by the foreign automaker. Initially the domestic partner was hand-picked by the government, but in the past ten years JVs have merely required government approval (Richet and Ruet 2008). During the period I study, JV enterprise plants produced essentially only foreign-brand vehicles, and the foreign partner was responsible for designing, controlling, and operating the plant. However, there is usually 50-50 profit share agreement (for more detailed discussion of how the JVs operate, see Section 6). Beijing explicitly intended the domestic partners to evolve into multinationals competing in foreign markets.

The JV policy was not systematically applied to other Chinese sectors, but other countries have taken similar approaches, including Malaysia, India, Russia, and a number of Latin American countries. Some research has found a positive effect of JVs on the innovative capabilities of local firms (e.g. Lyles and Salk 1996 and Mathews 2002). However, other work has found JVs to have negative effects on the partner firm, despite local managers and engineer learning (e.g. Inkpen and Crossan 1995, Doner 1991, Grieco 1984). In China, Gao (2004) finds negative impacts of JVs on firm innovation, and Jing and Zhou (2011) suggest that many JVs in a sector can lead to dependence on foreign technology.

China's protectionism likely exacerbated these incentive problems. Import tariffs of 180-220% through 1994, 70-150% through 2001, 30% through 2005, and 25% thereafter restricted the vast majority of Chinese consumers to vehicles produced in China. Appendix A Figure 1 shows that less than 0.5 million vehicles were imported until 2010, and since imports have risen - driven by SUVs - to a little over 1 million. Initially, the absence of competition enabled the few foreign firms manufacturing in China through JVs to use outdated technology, thus limiting the potential cost of any technology transfer (Moran 1998). In the early 2000s, 60% of domestic brand models were outdated foreign designs purchased or stolen from foreign automakers (Oliver et al. 2009). Subsequent policy required JVs to have "the capacity for manufacturing products which attain the international technological levels of the 1990s" as well as an R&D center (Walsh 1999).

During the 1990s, state-owned automakers were corporatized, largely separated from direct government control, and many were partially listed on stock exchanges (Andrews-Speed 2012). Deng and Ma (2010) estimate markups in Chinese auto industry between 1995 and 2001, and found that large automakers set high markups; Volkswagen, for example, had estimated markups of 42%, with a 41% market share in the late 1990s. Following WTO accession in 2001, the government gradually removed barriers to entry for both independent private firms and foreign firms establishing new JVs. In this period demand grew dramatically, and new foreign firm entry led to more competition and updated models (Oliver et al 2009). Although WTO terms forbid market access-technology transfer *quid pro quo*, the government continued to enforce the technology transfer requirements of its 1994 auto sector policy.

Beijing has called for "self-reliant Chinese car manufacturers who ranked among the 500 largest global firms" (NDRC 2004). Part of this effort throughout the reform period are repeated attempts consolidate the industry, and merge or shut down many of China's small automakers.[8] The auto industry is characterized by large economies of scale, which have eluded the Chinese firms thus far. Despite achieving a few large SOE mergers, the consolidation pushes were broadly unsuccessful; privately owned firms entered the market and provincial governments established new local state-owned automakers, ignoring the central targets (Oliver et al 2009). More recent policies emphasize the auto industry as a key locus of economic upgrading, and focus on independent R&D ("indigenous innovation", 自主创新) and "new energy" vehicles (State Council 2006, 2012).

In 2009, an industry analyst concluded:

> "Two-and-a-half decades have passed and dozens of such joint ventures have been built in China. But no domestic automaker has achieved what the government wanted. While some own-brand cars are built on platforms transferred from global automakers, almost all of the rest are products of the reverse engineering of international models. Some domestic firms continue to resort to outright copying" (Yang 2009).

Similarly, a study of patents found that local Chinese automakers lagged far behind in conventional power-train technologies (Medhi 2006).

Growth literature typically posits that income disparities across countries depend on varying rates of technology adoption. For example, Parente and Prescott (1994) theorize that barriers to technology adoption - including regulatory constraints, corruption, or threat of violence - increase the cost of adoption, accounting for much of the income disparity. But how this technology adoption occurs remains unclear. For Lucas (1993), the engine of growth is climbing the quality ladder through local industry exports. Melitz (2003) shows

[8]The Automotive Industry Policy of 1994 was quite specific, designating 8 companies that were permitted to manufacture passenger cars "The Big Three, Small Three and Mini Two" permitted to produce passenger cars were, in order: FAW, SAIC, Dongfeng, BAIC, TAIC, GAC, Changan and Ghizou Aviation. See State Council 1994.

that new export opportunities and intense competition create aggregate productivity gains by reallocating resources from less to more productive firms. This is consistent with the finding in Clerides, Lach and Tybout (1998) that more productive firms select into exporting, but exporting itself does not increase a firm's technical efficiency. Limited local markets, competition, and export-oriented industrial policy apparently allowed firms in the "East Asian Tigers" to learn quickly in order to compete in foreign markets.

Unlike Japan and Korea, China's automotive industrial policy was not successful. Foreign brands dominate the Chinese market (see Section 3), and the little exports thus far are concentrated in privately owned firms without JVs (see Section 6). China's high import tariffs and JV requirements are forms of infant industry protection. In general, there is no consensus in the literature about the effectiveness of infant industry policies (Grossman and Helpman 1994, Nunn and Trefler 2010). Models of infant industry protection and the effects of trade on growth depend on how firms learn (e.g. Melitz 2005, Young 1991, and Clemout and Wan 1970). In this paper, I present evidence of when firms *do not* learn, hopefully shedding some light on this debate.

2.2 The Fuel Economy Standards and Vehicle Quality

In 2004, China's National Development and Reform Commission announced that China would, for the first time, adopt fuel economy standards. The policy had two aims: 1) to decrease oil consumption for energy security purposes; and 2) to increase technology transfer by forcing foreign firms to bring more up-to-date technology to China (Wagner et al. 2009, UNEP 2010, Oliver et al. 2009).

There is a basic tradeoff between vehicle fuel economy and, primarily, weight, torque and horsepower. An automaker faced with fuel economy standards can build lighter, less powerful cars that will meet the standards without new technology. Alternatively, the automaker can maintain or improve quality by acquiring fuel efficiency technologies. These include discrete engine parts like catalytic converters and whole-vehicle design improvements in the power-train, aerodynamics and rolling resistance.[9] Importantly, high quality vehicles - particularly heavy and powerful ones - have higher profit margins than lower segments (IMF 2006).

Foreign automakers have faced stringent fuel economy standards in Japan and Europe for decades, and have developed technologies permitting heavy, powerful cars to meet those

[9]Other specific technologies include reducing transmission losses, direct fuel injection, variable valve timing, turbochargers, superchargers.

standards. Knittel (2011) examines the trade-offs in the U.S. auto industry between 1980 and 2006, establishing that decreasing weight in passenger cars by 10% is associated with a 4.2% increase in fuel economy, and decreasing horsepower by 10% is associated with a 2.6% increase in fuel economy. He documents that U.S. automakers improved fuel efficiency technology dramatically but used those improvements to increase engine power and weight but improve fuel economy only slightly.

Some of the technologies - particularly in the engine - are often outsourced to suppliers, but to integrate the technology and effectively model its trade-offs the branded automaker must invest in engineering and design competency, as well as the relationship with the supplier (Morris et al. 2004, Chanaron 2001). Industry analysis typically assumes that the locus of innovation is the branded automaker, especially for fuel efficiency technologies (Oliver Wyman 2013). Unfortunately, I do not have data on the fixed and variable costs of fuel efficiency technologies. However, the variable costs are not insignificant; Mckinsey (2012) estimates that new U.S. fuel economy standards will increase component costs in American vehicles by 20% between 2012 and 2020.

In general, fuel economy standards generate an incentive to down-weight certain classes of vehicles. Jacobsen (2013) and Anderson and Auffhammer (2014) show that down-weighting in response to fuel economy standards produced large negative welfare effects in the U.S., because when the fleet has widely varying weight, crashes are more likely fatal for passengers in small cars. While the standards in the U.S. and Europe are based on targets for an automaker's overall fleet, China and Japan use a weight-based step system that applies to each individual vehicle.[10] This generates the perverse incentive to meet standards by either increasing fuel economy within a class (potentially by decreasing weight) or jumping to a higher weight class with a more lenient standard. In Japan, weight-based standards are estimated to impose large safety costs (Sallee and Ito 2013). China is currently increasing the stringency of its standards, and is shifting to a fleet-based system. The policy agenda is now much more oriented towards using fuel economy and emissions standards to reduce urban pollution, rather than generate technology transfer (Shen and Takada 2014).

China's Phase 1 fuel economy standards were implemented in July 2005 for new models and January 2006 for continuing models. Phase 2 came into effect in January 2008 for new models, and January 2009 for continued models.[11] The Phase 2 standards are

[10] Wagner et al. (2009) suggest that because China had so many small manufacturers producing only one or two models, a fleet average approach was not meaningful. Oliver et al (2009) point out that "vehicle sales figures in China have been historically secret, unknown, and/or difficult to obtain, making a sales-weighted average approach unpractical."

[11] Phase III was phased in between 2012 and 2015. Phase III alters the previous program by adding

graphed in Figure 1, and Appendix A Table 1 lists the standards by weight class.[12] Phase 2 is more stringent than current U.S. standards, but much less stringent than Japanese and European standards (Appendix A Figure 2 compares standards across countries). The Chinese standards are designed to be "bottom heavy," meaning that they are stricter for heavier vehicle classes (An et al. 2011).

Before the standards, automakers selling vehicles in China did not have to report fuel economy. However, assessments of the standards have concluded that the initial 2006-07 standards were not binding (Wagner et al. 2009, Oliver et al. 2009, An et al. 2007). But Wagner et al. (2009) estimate that 32% of models in 2007-07 would not meet the Phase 2 standards. More generally, prior to the Phase 2 implementation, government inspection and enforcement was lax, particularly for domestic automakers. If automakers made a model's fuel economy public, they often provided no indication about the driving cycle (city vs highway driving). It is thus difficult to compare fuel economy before and after the standards. My interviews in 2013 at the the government-affiliated China Automotive Research and Technology Center (CATARC) in Tianjin, which has been partially responsible for developing fuel economy standards and testing vehicles, confirmed that meaningful enforcement of the standards and consistent fuel economy testing began in 2008-2009. My primary estimation therefore takes 2009 as the policy implementation year. Figure 1 shows the fuel economy reported for new vehicles in 2010 alongside the Phase 2 standards. Assuming accurate reporting, it seems that the vast majority of models meet the standards.

3 The Data and Descriptive Statistics

This paper is based on a unique, non-public dataset of all passenger vehicle sales in China between 1999 and 2012. Each observation is a model-year, and includes the ultimate Original Equipment Manufacturer (OEM), brand, model name, vehicle class, engine displacement, and powertrain (all in Chinese).[13] The data is from the State Council Development Research Center (DRC), which is the policy analysis organization for China's top-level state (i.e.

corporate average fuel economy targets to the weight-based system. According to the 2012 Energy-Saving and New Energy Vehicle Industrialization Plan, the goal is to achieve a fleet average of 6.9 L/100km by 2015, and 5.0L/100km by 2020.

[12]The Phase 2 standards are roughly equivalent to Euro IV. China uses the New European Driving Cycle (NEDC) testing method, rather than the CAFE method used in the U.S.

[13]OEM refers to the firms that design, assemble and brand vehicles such as Ford and Hyundai. Class is either city car, sedan, SUV, minivan, or van. Engine displacement is in liters, and is not used. Powertrain is either internal combustion engine, natural gas, electric, or hybrid electric.

not Party) governing apparatus. The sales data is quite reliable, as it originates in police registration data that is provided to the DRC.[14] In this section I describe the data, present summary statistics, and demonstrate parallel trends for foreign and domestic firms.

I acquired model-year characteristics through web scraping. The model characteristics are: price (MSRP), maximum torque (nm), peak power (kw), curb weight (kg), length (mm), height (mm), and fuel economy (l/100 km).[15] I convert price into dollars using the average monthly exchange rate that year, and all price figures are nominal. As discussed in Section 2.2, fuel economy is rarely reported and unreliable in the pre-policy period.

Vehicle torque, responsible for acceleration and power, is a useful measure of vehicle quality.[16] Torque depends not only on the engine but also transmission ratios, weight, and many other aspects of overall vehicle integration. A car with more torque will have a better driving feel, and usually better engineering and design. In my data, the correlation between torque and price for all model-years is 0.83. When torque is multiplied by a given speed (usually in rpm), it gives horsepower (usually in kilowatts). Power is the amount of energy the engine can produce and determines the top speed of the vehicle. Its correlation with price is 0.84, and with torque 0.9. I treat torque, power and price as measures of vehicle quality, but also show the effects of the policy on vehicle weight, height and length. In general, larger, heavier cars have more amenities and are safer. The correlation between weight and price in my data is 0.67.

I use brands as the unit of analysis in descriptive statistics and primary estimations. Examples of brands are Ford, Audi, BYD, and Roewe. To avoid confusion, I term brands "firm," but the reader should be aware that in many cases the firms I refer to are in fact subsidiaries of an OEM. While Ford and BYD are both their respective OEM's only brand, Audi is a Volkswagen subsidiary, and Roewe is a brand of Shanghai-government owned SAIC. I use brands because they are the unit of observation most relevant to understanding quality; design, engineering and final assembly generally take place at the brand (firm) level, rather than the OEM level. This is especially true in China, where some OEMs are JVs producing domestic and foreign brand vehicles, albeit at different plants. I show that my empirical

[14] I acquired this data in my capacity as a visiting scholar at the DRC (中国发展研究基金会), which was possible because of an invitation secured by Harvard Kennedy School Professor Anthony Saich from Lu Mai, the Secretary General of the DRC. The data itself was provided through the head researcher at DRC's Institute of Market Economy. I now have 2013 data, and will incorporate it in a future draft.

[15] The webscraping did not find characteristics for some model-years. There is coverage for 82% of models (slightly more for foreign models (88%) than domestic (73%), and slightly better in later years). Models without characteristics have much lower sales; the mean sales volume is 13,629 for models lacking characteristics data compared with 25,824 for models with characteristics data.

[16] Torque is the amount of force the engine can apply in a rotational manner, measured in nanometers.

results are robust to grouping at the OEM level, but focus descriptive statistics at the firm level.

Figure 2 compares foreign and domestic market share. The number of vehicles produced in China rose from just 0.6 million in 1999 to nearly 16 million in 2012. Variety increased as well; the number of models has increased fairly linearly from 23 in 1999 to 426 in 2012.[17] Figure 2 provides visual evidence for parallel trends between foreign and domestic firms in volume and market share in the years immediately preceding the 2009 policy. In the 2004-2006 period, domestic firms gained substantial market share.

The strong relationship between torque and price, as well as the marked difference in torque and price between foreign and domestic firms, are depicted in Figure 3. Figure 4 shows how foreign and domestic firm sales-weighted firm characteristics have diverged over time, specifically after 2009.[18] Domestic firms show slight decreases, while foreign firms steadily improve vehicle quality. These provide some visual evidence for parallel trends in sales-weighted characteristics in the years preceding the policy. Below I discuss more rigorous regression tests. Figure 5 shows 2010 sales and price figures for the the largest foreign (top graph) and domestic (bottom graph) firms.[19] The same graphs at the OEM level are in Appendix A Figure 7.

Summary statistics of the firms in my data are in Table 1, and of model characteristics in Table 2. In both tables, the first three columns divide the sample into three periods, the first two prior to the fuel economy standards (1999-2004 and 2005-2008) and the latter after the policy (2009-2012). This reveals average changes in the data around the policy and also offers a sense of how the market has changed over time. Column IV contains all years. Table 1 shows that the number of domestic firms nearly doubled over the course of the data, with most entry occurring prior to the 2009 policy. Average domestic firm sales volume doubled between each period, increasing from 52,000 vehicles per year in the 2005-08 period to 116,000 vehicles in the 2009-12 period. Similarly, average foreign firm sales volume increased from 146,000 per year to 320,000 per year. Amid this massive growth, domestic

[17] For this calculation, versions of the same model with different engine sizes are not treated as different models

[18] A firm j's sales-weighted torque (SWT) is calculated as follows, where i denotes model and t denotes year: $\text{SWT}_{i,t} = \sum_{i \in j} \left(\frac{s_{i,j,t}}{\sum_j s_{i,j,t}} \cdot \text{torque}_{i,j,t} \right)$. The figures show SWT averaged across firms within a firm type (foreign or domestic).

[19] The highest volume domestic firms are Wuling, with about 1.2 million vehicles sold in 2012, and then Chang'an, Chery, Great Wall, and BYD (in that order). Chang'an sold 0.8 million vehicles in 2012. However, Wuling is a JV between GM, SAIC and Liuzhou Wuling Motors, and Wuling is counted by GM as part of its China production. Volkswagen is the dominant foreign firm, at about 2.1 million vehicles in 2012. Hyundai follows, at around 0.8, and the next largest are Nissan, Toyota, Buick, Chevrolet, and Honda, in that order.

prices in nominal dollars have stayed essentially constant - thus decreasing in real terms - while foreign prices have increased significantly. For the full span of the data, the average foreign firm sales-weighted mean price is $24,200, while for domestic firms it is $10,800.

Table 2, where the model-year is the unit of observation, and characteristics are not sales-weighted, gives an average foreign model price of $26,500, compared with $12,200 for domestic models. Domestic Chinese model torque, power and weight increased between the first and second periods, but decreased or remained stable between the second and third periods (which bracket the fuel economy standards implementation). This contrasts with the foreign firms, for whom the means of all six characteristics increase between each period. However, none of the differences in means are significant, as characteristics within groups vary widely.

I estimate the relationship of characteristics to vehicle price using Equation 1, where j denotes firm and i denotes model.

$$Y_{it} = \alpha + \beta_1 \text{Domestic}_j + \beta_2 \text{Torque}_i + \beta_3 \text{Weight}_i + \beta_2 \text{Height}_i + \beta_2 \text{Length}_i + \delta' \mathbf{1} \mid \text{Class}_i + \varepsilon_{ijt}. \quad (1)$$

The results, shown in Table 3, indicate that there is a large and robust premium associated with torque; a one standard deviation increase in torque increases price by $11,500, or 50% of the average price. This relationship is consistent across the three periods (columns II-IV). The domestic firm discount increased over time; domestic firms were associated with a $3,300 discount between 1999 and 2004, and a $5,700 discount between 2009 and 2012. There is a large discount for SUVs relative to compact cars (the omitted class dummy), but there is no measurable relationship between the other classes and price. This may be because domestic firms have disproportionately increased their SUV sales relative to foreign firms, which is shown in Appendix A Figure 3.

The estimation strategy in Section 4 will compare domestic firms' response to the fuel economy policy with that of foreign firms. The results are the difference in the two types of firms' reaction to the policy. If foreign and domestic firms' model characteristics were on similar growth paths, the effects that I observe are more readily interpretable as reactions to the increase in fixed costs that domestic firms experienced but foreign firms did not. That is, the higher fixed cost to build high quality vehicles is like a "treatment." In Table 4, I present regressions that test for statistically different trends over time in model characteristics prior to the policy. The regressions, in which i indexes models, j indexes firms, and t indexes years, are of the form

$$Y_{it} = \alpha + \beta\left(\text{Year}_t \cdot \text{Domestic}_j\right) + \gamma_1 \text{Year}_t + \gamma_2 \text{Domestic}_j + \varepsilon_{ijt}, \tag{2}$$

where Year_t is a continuous variable ranging, in Panel A, from 2003 to 2008, and Domestic_j is an indicator for the firm being domestic (Chinese) rather than foreign. Y_{it} is a model-year characteristic, such as horsepower or price. Table 4 shows that there is no statistically significant difference in trends between foreign and domestic firms prior to the policy, except for length (column VI), which has a difference of 31 mm (relative to a sample average of 4,430 mm), significant at the 10% level. The large standard errors mean that I cannot rule out a difference in trends. However, the coefficients are an order of magnitude smaller than the treatment effects I demonstrate in Section 5. For example, the treatment effect on torque in my primary specification is 17 nm, compared to an estimated difference in growth path of -1.3 to 1.6 nm shown in Table 4.

This paper does not address auto parts suppliers. In recent years, automakers sometimes purchase as much as 70% of the vehicle value added from parts suppliers (Canis and Morrison 2013). However, key vehicle design and technological challenges, particularly from a fuel economy perspective, are accomplished at the automaker level. A passenger car includes at least 15,000 parts, which must fit perfectly and function consistently in order to meet Western consumer expectations. Although component suppliers are an important part of the overall automotive industry, they are a separate sector from branded automakers and are beyond the scope of this paper.

4 Empirical Strategy

My analysis of the impact of the fuel economy standards relies primarily on a differences-in-differences (DD) design. I compare foreign and domestic firms' vehicle characteristics before and after the 2009 fuel economy policy. I also exploit the staged policy for new and continuing models in a triple-difference specification.

The standard DD design involves two groups, one of which is subject to a treatment in the second of two time periods. If the two groups are ex-ante similar and have similar time trends, then inclusion of controls for treatment and state should yield an estimated coefficient on the treated state that is the average difference between the treatment group and the control group. However, in practice DD estimators pose two potential problems.

First, DD design will fail if the policy is endogenous to the group studied. The fuel economy standard affected both foreign and domestic firms, and I have been unable to identify other policies or market structure changes that would have affected domestic firms within the bandwidth of time in which I find an effect. Also, one of the policy's stated goals was to increase domestic firm technology quality. Therefore, endogeneity should work in the opposite direction than my results point.

The second issue is that serial correlation in variables may cause downward bias in the standard errors. This is especially problematic with relatively long time series and DD implementation via time fixed effects. As in most DD designs, the dependent variables here (e.g. model torque) are serially correlated. Pooling the data on either side of the treatment and clustering standard errors by group rather than time solves the problem, particularly when the number of groups is large (see Bertrand, Duflo and Mullainathan 2004, and Donald and Lang 2007). In my primary specification, I pool the data on either side of the cutoff with a bandwidth of three years around the policy, and cluster standard errors in 78 groups. In robustness tests I show that, among other things, using all years and including year fixed effects (as in most DD implementations) yields roughly the same results. I also demonstrate that conventional firm-year clusters do cause downward bias in standard errors.

My primary DD specification, where i is the vehicle model (e.g. the BYD F6 or the Chevrolet Spark), j the firm (e.g. Chery or Honda), and t the year, is as follows:

$$Y_{it} = \alpha + \beta \left(\text{Policy}_t \cdot \text{Domestic}_j\right) + \gamma_1 \text{Policy}_t + \gamma_2 \text{Domestic}_j + \lambda_j + \varepsilon_{ijt}. \tag{3}$$

The outcome of interest is Y_{it}, such as model torque or price. The indicator Policy_t is 1 if the year is 2009 or later, and 0 otherwise. The indicator Domestic_j is 1 if the firm is Chinese (e.g. BYD or Chery), and 0 if it is foreign (e.g. Nissan or GM). I include firm fixed effects λ_j, which should control for unobserved firm-specific variables related to characteristic choice. The primary specification requires the model sales volume to be at least 1,000 vehicles.

The coefficient of interest, β, gives $\left(\bar{Y}_{i=\text{Domestic},1} - \bar{Y}_{i=\text{Domestic},0}\right) - \left(\bar{Y}_{i=\text{Foreign},1} - \bar{Y}_{i=\text{Foreign},0}\right)$, or the effect of the policy on domestic firms relative to foreign firms. β indicates how domestic firms responded differently to the standards than foreign firms. The parallel trend assumption - that the error term is uncorrelated with the other variables - is not directly testable, but evidence in Section 3 on model characteristics supports it. Although the Chinese auto industry grew and changed dramatically between 2006 and 2012, the specification is valid if shocks affected both foreign and domestic firms. Placebo tests show that similar treatment effects do not appear until 2009.

The second specification is a triple-difference design, which is more robust than any DD approach (Imbens and Wooldridge 2007). I exploit the staged policy implementation; only new models were required to meet the standard in 2008, and then in 2009 the standard applied to both new and continuing models. Automakers sensitive to the policy may have changed new model but not continuing model characteristics in 2008. The primary specification is:

$$
\begin{aligned}
Y_{it} \quad = \quad & \alpha + \beta \left(\text{Policy}_t^{2008} \cdot \text{Domestic}_j \cdot \text{Continuing}_{it}\right) + \gamma_1 \left(\text{Policy}_t^{2008} \cdot \text{Domestic}_j\right) \\
& + \gamma_2 \left(\text{Policy}_t^{2008} \cdot \text{Continuing}_{it}\right) + \gamma_3 \left(\text{Continuing}_{it} \cdot \text{Domestic}_j\right) \\
& + \gamma_4 \text{Policy}_t + \gamma_5 \text{Domestic}_j + \gamma_6 \text{Continuing}_{it} + \lambda_j + \varepsilon_{ijt}.
\end{aligned} \tag{4}
$$

The Policy_t^{2008} variable is 1 if the year is 2008, and 0 if 2007 or 2006. In the primary specification, I use two years before the policy in order to have a larger sample size. Here, the interpretation of the coefficient of interest β is slightly more complicated; it is the effect of being a continuing model relative to a new model, netting out the change in means in firm type (domestic vs. foreign) and in time period (after vs. before the 2008 policy).

5 Effect of Fuel Economy Standards on Vehicle Characteristics

5.1 Differences-in-Differences Results

The differences-in-differences estimation finds that domestic firms responded to the 2009 fuel economy standard by manufacturing less powerful, cheaper, smaller, and lighter vehicles. Throughout my specifications and robustness tests, the effects on torque and price are the strongest and most significant, with the effects on weight and size smaller and less robust.

The results of my primary specification (Equation 2) on all six vehicle characteristics are in Panel A of Table 5. I find that the standards reduced vehicle torque in domestic models relative to foreign models by 17 nm, or about 12% of mean torque among domestic firms (significant at the 1% level). The partial effect of the policy on torque is 11 nm for foreign firms, and -6 nm for domestic firms. Note that because I use firm fixed effects, the partial effect of being a domestic firm on torque requires omitting these effects. This is shown in Table 9 column III; the partial effect of being domestic is -32 nm of torque before the policy and -52 nm after.

Domestic automakers reduced price by \$2,784 relative to foreign automakers, which is 23% of average domestic firm price and 13% of average price across all models (significant at the 1% level). The standards reduced power by 6.3 kw, or 8% of average power among domestic firms (significant at the 5% level). They reduced weight is reduced by 55 kg, and length by 91 mm, which are 4.3% and 2.1%, respectively, of the domestic firm averages (both significant at the 10% level). Panel B of Table 5 uses a bandwidth of two years around the policy, and finds quite similar results, albeit slightly smaller. As the effects on height and length are not robust, and are also not strong measures of quality, I omit them in subsequent tables.

The effect of the policy on all characteristics grows as the sample is restricted to models with increasing required sales volume. In Table 6, I show the increasing effect on price; with no sales volume requirement (column I) the effect is -\$1,616, significant only at the 10% level, but at a required sales volume of 5,000 vehicles (column IV), the effect is -\$3,453, significant at the 1% level. Appendix A Table 2 shows a similar pattern for all characteristics. For example, when sales volume is required to be more than 5,000 vehicles, the effect on weight is -92 kg, almost twice the magnitude of the coefficient in the primary specification.

Table 7 contains the triple-difference estimation using the 2008 implementation of the policy for new models.[20] The coefficient of interest gives the effect of being a continuing vs. a new model after vs. before the policy for domestic firms vs. foreign firms.[21] This coefficient is positive and significant for all four characteristics, showing that continuing models not subject to the policy were more powerful, more expensive, and heavier than new models for domestic firms relative to foreign firms. Note that the coefficients on the individual indicators and interactions are not direct effects.[22] The predictive margins of the policy's effect are graphed in Figure 6, where each line holds fixed whether the firm is domestic or foreign, and whether the model is continuing or new. Domestic firm new model torque decreased, while continuing models increased slightly. Foreign firm new model torque increased, while continuing model torque stayed roughly constant. Again, the firm fixed effects mean the that the level of torque is not meaningful, only the relative changes.

[20] In 2009 the standards applied to both new and continuing models, so it is impossible to do a similar exercise with the 2009 rule.

[21] The proportion of new models was slightly higher than average in the policy implementation year. The average number of new models among all firms per year between 2006 and 2012 is 13%, and 15% in 2008. For domestic firms, the average is 26%, and is also 31% in 2008.

[22] For example, the -17 nm effect of $\text{Policy}_t^{2008} \cdot \text{Domestic}_j$ on torque is the interaction of the policy and being domestic within new models (when Continuing_{it} is zero). The coefficient of 39 on Domestic_j is the effect of being domestic, when the other two indicators and firm fixed effects are zero.

I find across specifications that the policy's effect on weight and height is less statistically significant than its effect on the other characteristics. This reflects the weight-based standards, which create perverse incentives to either jump up a weight class or reduce weight within a class. The standards are also more at lenient at each weight class for SUVs and minivans (see Appendix A Table 1). Domestic automakers may have responded to the standards *both* by producing more SUVs, which are heavier, and by downsizing sedans and compact vehicles, which made them smaller. Domestic firms produce disproportionately more SUVs and minivans relative to foreign firms.[23] Appendix A Table 3 shows that with controls for vehicle class, the negative effect on weight is larger, but just barely insignificant. Domestic firms may have produced more SUVs because of the policy, or because foreign firms were relatively absent from the segment (e.g. AP 2013). The data do not permit establishing causality of the standards at the class level. The weight distribution of new sales has in general gotten less peaked; a higher proportion of vehicles are either very light or very heavy. This is shown in Appendix A Figure 8. As explained in Section 2.2, this in general reduces safety and has been shown to have large negative social welfare effects.

A potential alternative explanation for the effects I observe is that Chinese firms reduced price and vehicle quality to gain market share at the low end of the market, simultaneously but unrelated to the policy. However, they did not gain market share in any segment after the policy, making this possibility less likely. In Appendix A Figure 4, I show that for models priced below the 25th percentile, domestic firm market share was increasing rapidly until 2009, when it flattened out at a bit more than 80%. Foreign firm model characteristics did not measurably respond to the policy at all, instead continuing along their prior growth path. This is clear in Table 2 and Figure 4, and also from regressions comparing post-standard firm-type specific trends to prior trends.

5.2 Robustness

This section focuses on selected important robustness tests shown for torque in Tables 8 and 9. It also discusses the same tests for the other characteristics, and further robustness tests, which the reader can find in Appendix A.

Standard errors are clustered at the firm level in my primary specification to reduce their potential downward bias from serial correlation of the variables (Bertrand et al. 2004).

[23]Since 2006, when the first and non-binding standards were implemented, domestic firm SUV sales have roughly equalled sedan sales, whereas foreign firm sedan sales have been 6-10 times SUV sales since the 2009 policy, and more than 20 times SUV sales in earlier years.

Columns IV and V of Table 8 show that the effect on torque remains significant at the 1% level with no clusters and with firm-year clusters. Appendix A Table 4 shows four alternative assumptions on the errors for all four characteristics: homoscedasticity, robust (sandwich estimator), robust with year clusters, and robust with firm-year clusters. The coefficient of interest is highly significant in all four alternatives, for all four characteristics. The bias problem appears most severe with firm-year clusters.

Using all the data instead of a bandwidth around the policy yields a result similar to the primary specification (Table 8 column I). Appendix A Table 5 shows this larger bandwidth specification for all characteristics, and also illustrates the downward bias in standard errors that occurs in the commonly used DD design of including all years, year fixed effects, and clustering standard errors and at the firm-year level. This specification, in Panel B, yields significant coefficients for all characteristics, a misleading finding, and greater significance for power and weight, which are only moderately significant in the primary specification.

Columns II and III of Table 8 vary the required sales volume of models included in the regression. My primary specification, which requires at least 1,000 units sold, yields a coefficient on torque of -17 nm. When the required sales volume is only 100 vehicles, the coefficient declines to -12 nm, and when it is more than 5,000 vehicles, the coefficient is -19 nm. Appendix A Table 2 shows how for all four characteristics, the effect becomes stronger and more robust as the sales volume requirement increases.

I conduct placebo tests for every year possible with varying bandwidths. That is, I estimate the DD design as though the policy had been implemented in an alternative year. I did not find a significant effect in any, except moderate significance in placebo tests where the bandwidth includes the actual policy year of 2009. Columns VI-IX of Table 8 show the placebo test results for 2006, 2007, 2008, and 2010. In 2006, the coefficient is -.44 nm, and in 2007 it is -6.6 nm, neither with any significance. The 2008 and 2010 placebo tests yield impacts of -11 and -9 nm, both significant at the 10% level. Note that these bandwidths include the policy. Appendix A Table 6 shows the placebo tests for all four characteristics with the artificial year set to either 2005, 2006, 2007 or 2008. The reader may be concerned that the global recession coincided with the policy. However, China recovered quickly relative to other countries in the second half of 2009, returning to its pre-crisis growth path by 2010 (Diao et al. 2012).

Alternative individual and fixed effects are considered in Table 9, also using torque as the dependent variable. Column I shows that when I exclude the individual effects

($\text{Policy}_t, \text{Domestic}_j$) the coefficient on the interaction term increases in magnitude to -40 nm. With no interaction term, in column II, the effect of being a domestic firm is -44 nm, and policy has an insignificant effect of 4. I omit firm fixed effects here so that they do not soak up the negative effect of being domestic. Appendix A Table 7 shows these specifications for all the characteristics. The positive effect of being domestic on vehicle height is because a larger share of domestic firm production is SUVs. The primary specification without firm fixed effects produces a slightly stronger effect of the policy on domestic firm torque of -20 nm (column III). Both year and firm fixed effects gives a coefficient of -17 nm (column IV). Appendix A Table 8 shows that for all four characteristics, there is a significant negative effect of the policy regardless of whether I use year, firm and year, or no fixed effects. The coefficients are all of similar magnitude to my primary specification, but somewhat smaller with both firm and year fixed effects.

Column VI of Table 9 considers vehicle class fixed effects, in addition to firm fixed effects. There are four vehicle classes: compact, sedan, minivan, and SUV.[24] In the regression, the omitted class is compact; as expected, the other three classes have large positive effects on torque relative to compact cars. The effect of sedans or minivans relative to compacts is about 50 nm, and 82 nm for SUVs. The coefficients for all the characteristics decline slightly (shown in Appendix A Table 3); the coefficient on torque is now -15 nm. Finally, column VII uses OEM fixed effects, and also clusters standard errors at the OEM level. As discussed in Section 3, some OEMs have multiple brands, which are treated separately (and called firms) in the main specification. The number of groups is smaller at the OEM level; there are 69 groups (and so clusters) in OEM compared to 78 groups in firm. The coefficients and their significance are essentially unchanged with OEM fixed effects. The coefficient on torque is -16 nm, and the other characteristics are shown in Appendix A Table 3.

Further test in Appendix A include a bandwidth of only one year (data only from 2009 and 2008). New models already faced the standard in 2008, so even though the majority of models are continuing, I would expect that the result would be more diluted with this specification. Appendix A Table 9 shows that it generates very similar effects on torque and power as the primary specification. However, the other characteristics lose their significance. Appendix A Table 10 adds covariates to the specifications, including vehicle class, weight, height and length. As these are correlated with power and to a lesser degree torque, the effects decline and lose some of their precision.

[24] The DRC data included three additional classes. I include mini vehicles in the compact category, sedan hatchbacks in the sedan category, and pickup trucks in the SUV category.

Appendix A also contains a variety of robustness tests for the triple difference estimation. Table 11 shows that using alternative required sales volumes yields similar coefficients as the primary specification, with equal or more precision. Table 12 shows that the primary specification is sensitive to fixed effects; with no fixed effects at all, power and price lose their significance, but torque and weight remain positive and significant, albeit of smaller magnitude. However, with OEM fixed effects neither torque, power, nor price are significant; though weight actually increases slightly in magnitude *and* improves its significance from the 10% level to the 5% level. Thus there seems to be strong evidence that domestic firms down-weighted new models relative to continuing models in order to meet the 2008 standards. It may have been cheaper or faster to initially reduce weight in certain new models being prepared for production rather than alter the engine, transmission, and other components.

Finally, Appendix A Tables 13 and 14 show placebo tests for the triple difference design, using the years 2005, 2007, 2009, and 2011. In order to have adequate data, I require the sales volume to be more than 100 units. The placebo tests generate negative coefficients for 2005, and mostly positive coefficients for the later years, but all of these are insignificant except for price in 2007, which has a coefficient of $899 (less than 1/4 the estimated policy effect).

6 The Role of Joint Ventures and State Ownership

The domestic Chinese auto manufacturers can be divided along two dimensions: state ownership and joint venture (JV) status. This section addresses firms' performance and response to the standards along these two dimensions.

6.1 Background on JVs and Hypotheses about Firm Incentives

Much of the literature on Chinese economics demonstrates the inefficiency of state owned enterprises (SOEs) compared to private firms (e.g. Khandelwal et al. 2012, Bajona and Chu 2010, Jefferson et al. 2003, Lin et al. 1998). However, in some high-tech sectors, such as shipping, SOEs have become globally competitive, dominating the domestic market and making significant inroads into the the export market (see Appendix B). Recent work suggests Chinese SOEs are gaining in size and profits relative to the private sector. Hsieh and Song (2015) show that in the 2000s SOEs had faster total factor productivity growth than private firms and higher labor productivity, but lower capital productivity. My data includes firms that are majority owned by provincial governments (local SOEs), the central government (central SOEs), and privately owned firms. Many of the SOEs are partially listed on stock exchanges.

Both SOEs and privately owned firms have joint ventures (JVs) with foreign firms. A JV enterprise is the foreign firm's China operation; for example, all of BMW's China production occurs in a JV with Brilliance Auto, a domestic firm. But the JV manufacturing plant produces only BMW models. Brilliance receives 50% of the profits from each BMW sold, and provides a non-disclosed portion of the fixed and operating costs. The industry press suggests that the JVs failed to achieve technology transfer to domestic firms and that foreign partners remain the JVs' source of technology (Holmes et al 2013, Economist 2013, Sanford C. Bernstein 2013). Foreign firms operating in China source 25-75% of their parts in China, but the most advanced parts are still imported (Takada 2013, Yang 2008). Through case studies, Gallagher (2006) concludes that domestic Chinese companies have remained dependent on their foreign partners for technology, not learning how to innovate or design vehicles.

A bit of history illuminates this stylized fact. The first JV was announced in 1984 between SAIC, owned by the Shanghai government, and Volkswagen (VW). VW had substantial bargaining power and benefited from information asymmetry about auto manufacturing. Though the balance of power shifted as China's market grew, incomplete contracting and moral hazard continued to bedevil implementation of the JV arrangements (Thun 2004). To start fresh – and put pressure on VW – SAIC signed a second JV agreement with GM in 1997. GM aggressively marketed itself as a purveyor of useful technology, establishing a joint research center with SAIC called the Pan Asia Technical Automotive Center (PATAC). But PATAC was and continues to tweak existing GM-branded models for the Chinese market, not design new models. Further, most GM-branded models initially chosen for China were Daewoo or Opel designs, further distancing GM's Chinese operation from Detroit's state-of-the-art (Tang 2012).

A Wall Street Journal article concluded in 2012 that

> "Chinese auto regulators find themselves in a tight spot: their 30-year quest to build an industry dominated by Chinese car brands has backfired. The problem: joint ventures with foreign carmakers that have proven just a tad too comfortable."

According to He Guangyan, a former machinery industry minister, the JVs are "like opium" for the domestic firms (Dunne 2012).

China sought to exchange foreign access to the domestic market for technology transfer. Yet dynamically this industry structure may have reduced domestic firm innovation incentives. A domestic firm in a JV is disincentivized from designing substitutes to its foreign partner's vehicles because doing so would cannibalize the rents it earns from JV profits. To illustrates the intuition behind this tradeoff, consider the following stylized profit functions of domestic firm j with and without joint ventures, where ϕ is the technology quality of a model-year, and s is the share (typically 50%) of the foreign firm's profits that a firm with a JV earns:

$$\text{Firm without JV: } \pi_j = \sum_{i \in j} q_i(\mathbf{p}, \phi_i) \left(p_i - C_{i,\text{No } JV} \right) \tag{5}$$

$$\text{Firm with JV: } \pi_j = s\pi_{JV}^{foreign} + \sum_{i \in j} q_i(\mathbf{p}, \phi_i) \left(p_i - C_{i,JV} \right) \tag{6}$$

Suppose that ϕ is an increasing function of torque and horsepower: $\frac{\partial \phi_i}{\partial \text{Torque}_i} > 0; \frac{\partial \phi_i}{\partial \text{Power}_i} > 0$. The equilibrium vehicle price, p_i, increases with quality $\left(\frac{\partial p_i}{\partial \phi_i} > 0 \right)$, and also depends on all models in the market. The firm's cost function $(C_i = \mathcal{F}(\cdot, \phi_\text{i}))$ is also increasing in quality $\left(\frac{\partial \mathcal{F}}{\partial \phi} > 0 \right)$.

Suppose that fuel economy standard implementation requires that for a model with a given weight, the firm must invest some fixed additive amount to acquire fuel efficiency technology in order to meet the standards and maintain torque and power at their previous levels. Now $C_i = \mathcal{F}(\cdot, \phi_\text{i} + \text{F}_\text{j}(\phi_\text{i}) \mid \text{Weight}_\text{i})$.[25] Firms with JVs may have greater access to foreign firm technology than firms without JVs, so $F_{j \in JV} \leq F_{j \in No\ JV}$. The foreign firm already possesses the technology, so within its cost function $F_{foreign} = 0$. Thus holding other aspects of the cost function fixed, it may be cheaper for firms with JVs to provide a unit of quality (high torque and power) than firms without JVs under the standards; $\frac{\partial C_{i,JV}}{\partial \phi_i} \leq \frac{\partial C_{i,No\ JV}}{\partial \phi_i}$.

If domestic firms are price-takers, which is likely given their low concentration, then conditional on a given price vector for all models in the market, quantity sold should increase with quality and decrease with model price: $\frac{\partial q_i(\mathbf{p}, \phi_i)}{\partial \phi_i} > 0$ and $\frac{\partial q_i(\mathbf{p}, \phi_i)}{\partial p_i} < 0$. The first order conditions in quality are:

[25] For simplicity, suppose the fixed cost is spread equally across models and firms have equal numbers of models.

$$\text{Firm without JV: } \frac{\partial \pi_j}{\partial \phi_i} = q_i(\mathbf{p}, \phi_i)\left[\frac{\partial p_i}{\partial \phi_i} - \frac{\partial C_{i,No\ JV}}{\partial \phi_i}\right] + \frac{\partial q_i(\mathbf{p}, \phi_i)}{\partial \phi_i}(p_i - C_{i,No\ JV}) + \sum_{k \neq i \in j}\left[\frac{\partial q_k(\mathbf{p}, \phi_k)}{\partial \phi_i}(p_k - C_{k,No\ JV})\right] \tag{7}$$

$$\text{Firm with JV: } \frac{\partial \pi_j}{\partial \phi_i} = s\frac{\partial \pi_{foreign,\ JV}}{\partial \phi_i} + q_i(\mathbf{p}, \phi_i)\left[\frac{\partial p_i}{\partial \phi_i} - \frac{\partial C_{i,JV}}{\partial \phi_i}\right] + \frac{\partial q_i(\mathbf{p}, \phi_i)}{\partial \phi_i}(p_i - C_{i,JV}) + \sum_{k \neq i \in j}\left[\frac{\partial q_k(\mathbf{p}, \phi_k)}{\partial \phi_i}(p_k - C_{k,JV})\right] \tag{8}$$

Using the assumptions outlined above, the foreign firm's profit decreases in a competitor's quality $\left(\frac{\partial \pi_{foreign,\ JV}}{\partial \phi_i} < 0\right)$. The domestic firm's investment in own quality reduces its marginal profit from the JV.[26]

Is the equilibrium ϕ for a firm with a JV greater than that for a firm without a JV? Holding all else equal between the two types of firms, this depends on whether the negative effect on ϕ of access to the foreign firm's profits outweighs the positive effect of a lower technology acquisition cost:

$$\phi_{i,JV} > \phi_{i,No\ JV} \text{ if } s\left[\frac{\partial \pi_{foreign,\ JV}}{\partial \phi_i}\right] - \frac{\partial C_{i,JV}}{\partial \phi_i} > -\frac{\partial C_{i,,No\ JV}}{\partial \phi_i} \tag{9}$$

where the the first term has a negative sign, and the second two have positive signs (recall that $\frac{\partial C_{i,JV}}{\partial \phi_i} < \frac{\partial C_{i,,No\ JV}}{\partial \phi_i}$). In the following section, I try to test whether $\phi_{i,JV} > \phi_{i,No\ JV}$ or vice versa.

6.2 Descriptive Statistics

This section shows that private firms have achieved substantially better sales and revenue growth than state-owned firms, and have also dominated China's small volume of passenger vehicle exports. Domestic firms with JVs have higher sales and revenue than firms without JVs, but almost all of the exporting is done by firms without JVs. As few state-owned firms do not have JVs, and the JVs are not exogenously assigned, the poor performance of domestic firms with JVs is difficult to disentangle from the inefficiencies of state ownership. However, I attempt to do so using the small number of SOEs without JVs and private firms with JVs.

[26] All firms have the same variable cost of producing more fuel efficient vehicles.

Table 10 is a matrix of the number of firms (brands) and OEMs in each category. At the firm level, of the 43 SOEs, 37 have a JV. Of the 25 privately owned firms, only 3 have a JV. The correlation between state ownership and having a JV is 0.7. In the estimations below, I isolate firms that fall into the non-SOE, JV cell and the private, non-JV cell, but the reader should keep in mind that there are few firms in these categories.

The top left graph of Figure 7 shows that central SOEs, local SOEs, and private domestic firms have experienced quite similar sales volume trajectories since 2002. However, the bottom left graph shows that since 2005, private firms have experienced much higher revenue growth and today have annual revenue that is twice the level of either local SOEs or central SOEs. There does not seem to be any appreciable difference between local and central SOEs.[27] The right-hand graphs show that firms with JVs have experienced higher sales volume and much higher annual revenue than firms without JVs. This is partly because firms without JVs export a large fraction of their production. All four graphs contrast with Figure 8, which shows sales volume and revenue for foreign firms (note the difference in scale).

Exporting is strongly associated with firm productivity and competitiveness, (Melitz and Redding 2014, Giles and Williams 2000, Wakelin 1998). It is also an explicit Chinese auto industrial policy goal (State Council 2009). Yet total domestic firm exports in 2012 were 0.6 million vehicles compared to production for domestic consumption of about 6 million vehicles. Although exports are increasing rapidly, it is clear that the industry is far from meeting government export targets (Roland Berger 2013). One reason for the failure to export is a number of high profile Western crash test failures. In 2007, Germany and Russia tested Chinese sedans made by Brilliance Jinbei and Chery, respectively. The former crash test was described by the German officials as "catastrophic," while the Russian testers described the performance as among the worst it had ever encountered (Osborn 2007).

Since 2008, private firms and local SOEs without JVs have been responsible for almost all passenger vehicle exports, depicted in Figure 3.9. [28] The private and local SOEs without

[27] I estimate revenue by multiplying each model's sales volume by its price, and then summing annually over brands within categories.

[28] The biggest exporters are Great Wall (privately owned, Hebei province-based, listed on the Shanghai stock exchange with no JV), Chery (SOE of the Anhui provincial government with no JV), Geely (privately owned, listed on the Hong Kong stock exchange with no JV), JAC Motors (SOE majority owned by the Anhui provincial government and partially listed on the Shanghai stock exchange with no JV), and Lifan (privately owned, listed on the Shanghai stock exchange with no JV). My classification of JV status is by year of sales and ends in 2012. Some companies have since established JVs. Chery, after many previous abortive attempts to form JVs, began producing vehicles through a JV with an Israeli company under the brand name Qoros in 2013, and in 2012 allied with Tata to produce Jaguar Land Rover models in China from 2014.

JVs are very small, so their exports as a percentage of sales is high. Between 2008 and 2012, private firms without JVs exported 10-20% of their total sales, and local SOEs without JVs exported 10-30%.

Descriptive statistics offer no obvious differentiation in model characteristics across firm types. Appendix A Table 15 shows average model characteristics by firm ownership type and JV status. Appendix A Figure 5 depicts domestic brand sales-weighted characteristics over time. There are no significant differences across private and state-owned firms or firms with and without JVs. Central SOE models on average are somewhat less powerful and command lower prices, but high variation within categories means that the differences in means are not significant. For example, the mean model price between 2009 and 2012 for private firms was \$12,500, for central SOEs \$11,600 and for local SOEs \$12,700. Mean torque was 151 nm for private firms, 137 nm for central SOEs, and 152 nm for local SOEs.

6.3 Response to the Fuel Economy Standards by Firm Type

I evaluate whether incentives to innovate and acquire technology vary by firm type using the DD design proposed in Section 4, estimated on subsamples of domestic firms. I find that the strong negative effect of the policy on measures of quality appears concentrated in firms with JVs, as well as in SOEs. First, I perform regressions on separate subsamples (Table 11), and then combine them into a single specification (Table 12).

The dependent variables in Table 11 are torque in the left panels, and price in the right panels.[29] Columns I(a)-I(c) include only domestic firms with JVs and foreign firms; I(a) includes all such firms, I(b) only state-owned firms with JVs, and I(c) only privately owned firms with JVs. The coefficients on the interaction term are all negative, significant, and of at least as large a magnitude as the primary specification with all firms. Specification III considers SOEs, and specification V considers private firms. Looking down the first column, the strongest negative impact of the policy is for the subset of firms with JVs. Columns III(b) and V(b) show that for the subset of SOEs without JVs and privately owned firms without JVs, the coefficient is smaller and less precise. Further, it seems that private firms reduced model maximum torque more than SOEs in response to the policy; that is, the coefficients in specification V are more negative than those in specification III.

The right-hand panels of Table 11 conduct the same exercise with price as the dependent variable. In column (a), the strongest result is for the subset of firms with JVs. This

[29]These regressions do not include firm fixed effects because the number of firms in certain categories is quite small.

is also clear in comparing SOEs with and without JVs (IV(b-c)) and private firms with and without JVs (VI(b-c)). Firms with JVs reduced model price by \$3,458 relative to foreign firms after the policy, compared to \$2,791 for SOEs without JVs and \$2,586 for privately owned firms without JVs. SOEs and privately owned firms with JVs, in contrast, decreased price by \$3,378 and \$3,750, respectively. Here there is no appreciable difference betweenSOE and private firm price reduction.

I combine these effects into a single regression in Table 12.[30] I interact the policy with indicator variables for firm type and firm fixed effects. Column I shows that firms with a JV reacted more strongly than firms without a JV to the policy, relative to foreign firms. For firms with a JV, the interaction coefficient is -24 nm, significant at the 1% level. For firms without a JV it is -12 nm, significant at the 10% level. A similar result for price is in column IV. Columns II and V show that SOEs decreased torque and price much more than private firms; the coefficient on the interaction for price, for example, is -\$3,473 for SOEs and -\$1,951 for private firms. Columns III and VI subdivide firms without JVs into SOEs and privately owned firms. The policy's effect on SOEs without JVs is much more negative and more precise than that on private firms.

Wald tests on the Table 12 regressions reject the hypothesis that the coefficients on the interactions with price as the dependent variable are equal at the 10% level. However, I am not able to reject the hypothesis that they are equal for the torque specifications. These regressions use a stringent standard error assumption, clustering at the firm level. When I cluster at the firm-year level, as is often done in DD designs, I can reject the null that firms with and without JVs responded similarly to the policy with 95% confidence (p-value of 0.02) for torque as well as price. This is also true when I cluster at the year level or do not cluster at all.

In sum, SOEs with JVs appear primarily responsible for the domestic firm response to the policy of reducing model quality and price. Private firms without JVs responded the least to the policy, though the results for private firms are in general less precise. The equilibrium quality choice for firms without JVs after the policy is higher than for firms with JVs, or in the terminology of the toy model above, $\phi_{i,JV} < \phi_{i,No\ JV}$. This is consistent with a story in which the negative effect of own ϕ_i on the foreign partner's profits $\left(\frac{\partial \pi_{foreign,\ JV}}{\partial \phi_i}\right)$ outweighs any technology acquisition cost advantage that the domestic firm with a JV may have $\left(\frac{\partial C_{i,JV}}{\partial \phi_i} < \frac{\partial C_{i,,No\ JV}}{\partial \phi_i}\right)$.

[30] Appendix A Table 16 conducts the same regressions as in Table 12, for weight and power, with analogous results.

7 Conclusion

Using a novel and reliable data set, I assess how the fuel economy standards affected the model characteristic decisions of domestic Chinese automakers. Through a differences-in-differences design, I show that domestic Chinese firms responded to the 2009 implementation of fuel economy standards by reducing the torque, horsepower, weight, and price of their models. A triple differences design exploiting the staged policy for new and continuing models in 2008-09 finds that when domestic firms' continuing models were not yet subject to the policy, they were more powerful, more expensive, larger, and heavier than new models.

I then turn to the relative performance of Chinese firms by ownership and JV status. I show in a simple model that domestic firms might be disincentivized from producing substitutes for their foreign partners' models, even when they have a lower cost of technology acquisition than domestic firms without JVs. Competing with the foreign partner would cannibalize the domestic firm's share of foreign brand profits. I show that SOEs with JVs were primarily responsible for the negative effects of the policy on domestic firm quality and price. The negative effect of having a JV appears stronger than the negative effect of being state-owned, consistent with a story in which the negative effect of increasing own quality on the firm's share of JV profits outweighs any technology acquisition cost advantage that the firm reaps from its JV.

Conventional trade models, such as McGrattan and Prescott (2009, 2010) grossly overestimate both FDI inflows to and outflows from China, due to an assumption that foreign firms bring their technological capital to China, which Chinese firms accumulate. When Holmes, McGrattan and Prescott (2013) add China's requirement that foreign firms transfer technology in order to invest, they are much better able to match their multicountry dynamic general equilibrium model to moments in the data. FDI decreases when foreign firms must transfer technologies. They also find that JV-owned patents tend not to extend beyond China's borders; their primary case study is GM's patents with SAIC. They conclude that less foreign capital enters due to the "technology capital tax," and Chinese firms prefer to appropriate the foreign capital rather than innovate themselves. This is precisely what I observe in China's auto sector: foreign firms bring minimum technology to China because they cannot protect their intellectual property. Chinese firms, especially those with joint ventures, do little innovation on their own because a distorted market structure disincentivizes them from acquiring technology.

Table 1: Sales Volume and Firm Sales-Weighted Price ('000s) by Firm Type

	I. 1999-2004		II. 2005-2008		III. 2009-2012		IV. All Years	
	Mean (sd)	N	Mean (sd)	N	Mean (sd)	N	Mean (sd)	N
			A. All Firms					
# Active Firms	**-**	45	**-**	78	**-**	86	**-**	94
Sales Volume	22.7 (29.0)	81	52.1 (89.5)	162	116 (192)	201	75.3 (148)	444
Sales-Wgtd Price	10.6 (8.2)	56	10.7 (7.0)	124	11.2 (8.1)	167	10.8 (8.0)	347
			B. Domestic (Chinese)					
# Active Firms	**-**	27	**-**	52	**-**	61	-	68
Sales Volume	22.7 (29.0)	81	52.1 (89.5)	162	116 (192)	201	75.3 (148)	444
Sales-Wgtd Price	10.6 (8.2)	56	10.7 (7.0)	124	11.2 (8.1)	167	10.8 (8.0)	347
OEM has JV	**-**	15	**-**	27	**-**	35	-	40
Sales Volume	24.4 (32.9)	42	53.8 (99.0)	87	118 (221)	115	79 (168)	244
Sales-Wgtd Price	9.9 (7.1)	29	10.2 (7.2)	64	11.3 (9.9)	100	10.7 (8.6)	193
Privately Owned	**-**	11	**-**	22	**-**	23	-	27
Sales Volume	13.5 (18.9)	37	32.7 (39.6)	67	97.1 (124)	77	56.2 (91.9)	181
Sales-Wgtd Price	10.7 (7.1)	22	12.0 (6.8)	52	10.8 (6.3)	63	11.2 (7.1)	137
Central SOE	**-**	10	**-**	17	**-**	21	-	38
Sales Volume	34.5 (36.2)	28	60.4 (75.7)	54	102 (149)	71	74.8 (115)	153
Sales-Wgtd Price	9.3 (7.0)	23	10.1 (7.8)	41	11.7 (12.0)	58	10.7 (9.9)	122
Local SOE	**-**	6	**-**	13	**-**	17	-	29
Sales Volume	23.3 (28.9)	16	72.9 (144)	41	160 (305)	53	108 (234)	110
Sales-Wgtd Price	12.9 (6.7)	11	9.2 (5.8)	31	11.0 ($5.4)	46	10.6 (5.7)	88
			C. Foreign (Non-Chinese; 100% have JVs)					
# Firms	**-**	18	**-**	26	**-**	25	-	26
Sales Volume	82.7 (123)	73	146 (173)	89	320 (383)	96	193 (281)	258
Sales-Wgtd Price	19.2 (13.2)	71	23.4 (15.4)	85	29.0 (17.3)	91	24.2 (160)	247

Note: This table shows means of firm sales volume (number of vehicles) and sales-weighted price ('000s of nominal US dollars at contemporary exchange rates). Sales volume is the average across firms of each firm's average annual vehicle sales over the specified time period, where each observation is a firm-year. The sales-weighted price is the mean annual sales weighted price of a firm's models, which is then averaged across firm-years. Prices are in nominal US dollars, at the average annual contemporary exchange rate. In Columns I-III, the mean is taken across firm-years for all firms active in the period specified. JV= joint venture between foreign and domestic firm. SOE=state owned enterprise. I define firm at the brand level; a parallel table at the OEM level can be found in Appendix A.

Table 2: Model Characteristics by Firm Type

	I. 1999-2004		II. 2005-2008		III. 2009-2012		IV. All Years	
	Mean (sd)	N	Mean (sd)	N	Mean (sd)	N	Mean (sd)	N
A. All Firms								
Max Torque (nm)	160 (59.3)	280	173 (65.1)	916	177 (63.2)	1646	174 (63.6)	2842
Max Power (kw)	82.0 (31.8)	282	90.4 (34.8)	922	96.1 (33.9)	1651	92.9 (24.2)	2855
Weight (kg, ’000s)	1.27 (0.32)	276	1.34 (0.32)	899	1.37 (0.30)	1587	1.35 (0.31)	2762
Height (m)	1.51 (0.14)	285	1.55 (0.15)	916	1.55 (0.16)	1640	1.54 (0.16)	2841
Length (m)	4.37 (0.47)	285	4.41 (0.44)	916	4.45 (0.40)	1641	4.43 (0.42)	2842
Price (’000s)	20.0 (13.5)	300	19.9 (16.2)	931	22.0 (17.1)	1654	21.1 (16.5)	2885
B. Domestic (Chinese) Firms								
Max Torque (nm)	129 (50.0)	78	151 (57.0)	350	147 (46.0)	653	147 (50.3)	1081
Max Power (kw)	65.5 (26.5)	80	76.2 (27.8)	354	79.0 (22.4)	658	77.1 (24.8)	1092
Weight (kg, ’000s)	1.16 (0.35)	70	1.30 (0.35)	335	1.29 (0.28)	617	1.29 (0.31)	1022
Height (m)	1.54 (0.19)	77	1.61 (0.19)	344	1.59 (0.20)	643	1.59 (0.20)	1064
Length (m)	4.19 (0.58)	77	4.33 (0.50)	344	4.35 (0.43)	644	4.33 (0.47)	1065
Price (’000s)	12.2 (7.64)	87	12.1 (8.45)	354	12.3 (6.70)	651	12.2 (7.38)	1092
C. Foreign (Non-Chinese) Firms								
Max Torque (nm)	172 (58.4)	202	186 (66.3)	566	197 (64.9)	993	191 (65)	1761
Max Power (kw)	88.5 (31.5)	202	99.3 (35.8)	568	107 (35.4)	993	103 (36)	1763
Weight (kg, ’000s)	1.30 (0.30)	206	1.37 (0.29)	564	1.41 (0.31)	970	1.38 (0.31)	1740
Height (m)	1.50 (0.12)	208	1.51 (0.11)	571	1.52 (0.12)	997	1.52 (0.12)	1777
Length (m)	4.44 (0.40)	208	4.46 (0.40)	572	4.52 (0.36)	997	4.50 (0.38)	1777
Price (’000s)	23.1 (14.1)	213	24.7 (17.9)	577	28.3 (18.8)	1003	26.5 (18.1)	1793

Note: This table shows means of firm model characteristics. The reported mean is the average across firms of each firm’s average annual characteristic over the specified time period, where each observation is a firm-year. Prices are in nominal US dollars, at the average annual contemporary exchange rate. The unit of observation is the model-year. In the regressions, height is in millimeters. JV= joint venture between foreign and domestic firm. SOE=state owned enterprise. I define firm at the brand level. A parallel table at the OEM level, as well as a table where statistics are broken down by domestic firm ownership, can be found in Appendix A.

Table 3: Determinants of Vehicle Price by Time Period

Dependent Variable:	Price (current dollars)			
Time Period:	I. All years	II. 1999-2004	III. 2005-2008	IV. 2009-2012
$Domestic_j$	**-5103*** **	**-3331*** **	**-4176*** **	**-5657*** **
	(476)	(1207)	(670)	(623)
$Torque_i$ (nm)	**182*** **	**137** **	**201*** **	**178*** **
	(12)	(54)	(23)	(16)
$Weight_i$ (kg)	**16*** **	**14**	**11*** **	**20*** **
	(3.1)	(12)	(3.4)	(4.9)
$Height_i$ (mm)	**-10*** **	**-1.5**	**-5.9* **	**-9.8*** **
	(2.8)	(9.8)	(3.5)	(3.7)
$Length_i$ (mm)	**-7.6*** **	**-1.1**	**-8.1*** **	**-7.6*** **
	(1.3)	(3.5)	(1.8)	(1.7)
$\mathbf{1}\|Minivan_i$	**-370**	**-2411**	**572**	**-2220**
	(761)	(2074)	(946)	(1465)
$\mathbf{1}\|SUV_i$	**-2802*** **	**-7532*** **	**-3258* **	**-3265** **
	(950)	(2616)	(1818)	(1297)
$\mathbf{1}\|Sedan_i$	**720**	**1866**	**2709*** **	**-1334** **
	(523)	(1172)	(944)	(649)
N	2720	267	883	1570
R^2	.74	.69	.73	.76

Note: This table reports regression estimates of the relationship between price and vehicle characteristics (Equation 1). The Domestic variable is 1 if the brand is domestic (Chinese), and 0 if foreign. There are fixed effects for 4 vehicle classes: Compact, Minivan, SUV and Sedan (Compact is omitted). The unit of observation is the model-year. There are no brand or year fixed effects. Standard errors are robust and clustered by brand-year. 1999 $\leq$ Year $\leq$ 2012; *** indicates $p < .01$.

Table 4: Parallel trends among foreign and domestic firms prior to the policy

A. All Characteristics, 2003 $\leq$ **Year**$_t$ $\leq$ 2008

Dependent Variable:	I. Price (nom. $)	II. Torque (nm)	III. Power (kw)	IV. Weight (kg)	V. Height (mm)	VI. Length (mm)
$\text{Year}_t \cdot \text{Domestic}_j$	**-332**	**1.6**	**.56**	**22**	**4.4**	**31***
	(594)	(2.6)	(1.4)	(14)	(6.1)	(18)
Year_t	541	2.1	2.2***	7.6	1.4	13
	(347)	(1.5)	(.79)	(7.6)	(3.5)	(11)
Domestic_j	653111	-3160	-1143	-44947	-8678	-62417*
	(1190890)	(5199)	(2714)	(27392)	(12279)	(36948)
N	1113	1086	1092	1067	1090	1090
R^2	.15	.077	.12	.021	.081	.036

B. Alternative Specifications using Torque as Dependent Variable

Test:	VII. 2005-09	VIII. Firm f.e.	IX. Cluster s.e. by firm	X. Cluster s.e. by firm-yr	XI. Firm f.e., cluster s.e by firm-yr
$\text{Year}_t \cdot \text{Domestic}_j$	**-3.1**	**-1.3**	**1.6**	**1.6**	**-1.3**
	(4.2)	(2.1)	(2.4)	(3.4)	(2.3)
Year_t	.26	2.4**	2.1	2.1	2.4
	(2.5)	(1.1)	(1.6)	(2.5)	(1.7)
Domestic_j	6242	2630	-3160	-3160	2630
	(8469)	(4142)	(4723)	(6890)	(4621)
Firm f.e.	N	Y	N	N	Y
N	916	1086	1086	1086	1086
R^2	.067	.53	.077	.077	.53

Note: This table reports regression estimates testing whether the model characteristics of foreign and domestic firms were on different growth paths prior to the 2009 fuel economy policy (Equation 2). Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. The variable Year_t is continuous. The unit of observation is the model-year. Standard errors are OLS unless otherwise specified. *** indicates $p < .01$.

Table 5: Differences-in-Differences Estimation of the Fuel Economy Standard's Impact on Domestic vs. Foreign Model Characteristics

A. Bandwidth of 3 years around 2009 policy (primary specification)

Dependent Variable:	I. Torque (nm)	II. Power (kw)	III. Price (nom. $)	IV. Weight (kg)	V. Height (mm)	VI. Length (mm)
$\text{Policy}_t \cdot \text{Domestic}_j$	**-17***	**-6.3**	**-2784***	**-55***	**-18**	**-91***
	(5.3)	(2.8)	(763)	(32)	(21)	(52)
Policy_t	11***	5.9***	2821***	29**	14***	30
	(3.5)	(1.9)	(627)	(14)	(3.8)	(23)
Domestic_j	59***	70***	4479***	248***	-39***	437***
	(2.7)	(1.5)	(488)	(11)	(2.9)	(18)
Firm f.e.	Y	Y	Y	Y	Y	Y
N	1646	1651	1653	1599	1630	1631
R^2	.5	.48	.63	.47	.39	.44

B. Bandwidth of 2 years around 2009 policy

Dependent Variable:	VII. Torque (nm)	VIII. Power (kw)	IX. Price (nom. $)	X. Weight (kg)	XI. Height (mm)	XII. Length (mm)
$\text{Policy}_t \cdot \text{Domestic}_j$	**-16***	**-5.4**	**-2121**	**-47**	**-9.9**	**-74**
	(4.6)	(2.7)	(801)	(29)	(21)	(50)
Policy_t	7.8***	3.7*	1708**	15	12***	7.5
	(2.9)	(2)	(688)	(15)	(4.2)	(25)
Domestic_j	53***	67***	2979***	221***	-35***	377***
	(2.2)	(1.5)	(516)	(11)	(3.2)	(19)
Firm f.e.	Y	Y	Y	Y	Y	Y
N	1088	1088	1079	1047	1069	1070
R^2	.49	.49	.63	.46	.34	.44

Note: This table reports regression estimates of the effect of the 2009 fuel economy standards on model characteristics, with a bandwidth of three years around 2009 policy (Equation 3). Sales volume is the number of units sold of that model-year vehicle. Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. Policy_t is 1 if the year is 2009 or later, and 0 if 2008 or before.. The unit of observation is the model-year. Only models with at least 1,000 units sold are included. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 6: Differences-in-Differences Estimation of the Fuel Economy Standard's Impact on New Vehicle Price by Model Sales Volume

Dependent Variable: Price (nominal dollars)				
Min. Model Sales Volume:	I. 0	II. 500	III. 1,000	IV. 5,000
$\text{Policy}_t \cdot \text{Domestic}_j$	**-1616***	**-2459*****	**-2784*****	**-3453*****
	(902)	(675)	(763)	(1232)
Policy_t	2560***	2730***	2821***	3589***
	(654)	(485)	(627)	(1075)
Domestic_j	7740***	4258***	4479***	-11010***
	(509)	(397)	(488)	(2255)
Firm f.e.	Y	Y	Y	N
N	2078	1775	1653	1177
R^2	.64	.64	.63	.21

Note: This table reports regression estimates of the effect of the 2009 fuel economy standards on model price, with a bandwidth of three years around 2009 policy (Equation 3). Sales volume is the number of units sold of that model-year vehicle. Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. Policy_t is 1 if the year is 2009 or later, and 0 if 2008 or before. Regressions IV and V omit brand dummies because they generate collinearity with the variables of interest. The unit of observation is the model-year. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 7: Triple Difference Estimation of the Fuel Economy Standard's Impact on New Vehicle Characteristics (exploiting the 2008 implementation for new models, not continuing models)

Dependent Variable:	I. Torque (nm)	II. Power (kw)	III. Price (nom. $)	IV. Weight (kg)
$\text{Policy}_t^{2008} \cdot \text{Domestic}_j \cdot \text{Continuing}_i$	**20****	**8.6****	**4020*****	**114***
	(4.5)	(1.8)	(312)	(30)
$\text{Policy}_t^{2008} \cdot \text{Domestic}_j$	-17**	-4.8***	-3295***	-110*
	(2.9)	(.39)	(188)	(29)
$\text{Domestic}_j \cdot \text{Continuing}_i$	.068	-.28	-855	-46
	(3.7)	(1.5)	(430)	(26)
$\text{Policy}_t^{2008} \cdot \text{Continuing}_i$	-9.3*	-8.4	-1623***	-21**
	(3)	(4.7)	(159)	(3.9)
Policy_t^{2008}	8.9**	8*	2910**	23*
	(1.8)	(2.4)	(381)	(7.1)
Domestic_j	39***	61***	3799**	258***
	(1.2)	(1.9)	(532)	(3.2)
Continuing_i	-6.9	-1.8	23	27**
	(3.2)	(4.4)	(40)	(4)
Firm f.e.	Y	Y	Y	Y
N	638	641	646	626
R^2	.53	.52	.63	.55

Note: This table reports regression estimates of the effect of the 2008 fuel economy standards on model characteristics (Equation 4). The 2008 policy applied only to new models, not continuing models. Policy_t^{2008} is 1 if the year is 2008, and 0 if 2007 or 2006. Continuing_i variable is 1 if the model is a continuing model in 2008 (i.e. one that was already sold in 2007, like the VW Jetta, and 0 if the model is new, like the Great Wall Peri. Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. The unit of observation is the model-year. Only models with at least 1,000 units sold are included. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 8: Key Robustness Tests of Difference-in-Difference Estimation of the Fuel Economy Standard's Impact on New Vehicle Torque Part 1

Dependent Variable: Torque (nm)		Model sales volume		Standard error clustering		Placebo test with artificial policy at year			
Test:	I. All yrs (1999-2012)	II. >100	III. >5000	IV. None (robust)	V. Firm-year	VI. 2006	VII. 2007	VIII. 2008	IX. 2010
$Policy_t \cdot Domestic_j$	**-17****	**-12****	**-19*****	**-17*****	**-17*****	**-.44**	**-6.6**	**-11***	**-9***
	(6.9)	(5.5)	(6.1)	(4.4)	(3.7)	(7.3)	(5.6)	(5.9)	(5.2)
$Policy_t$	15***	11***	13***	11***	11***	3.2	5.1	6.3*	8.1**
	(5.2)	(3.2)	(3.8)	(3.1)	(2.7)	(5.1)	(3.4)	(3.3)	(4)
$Domestic_j$	65***	62***	-34***	59***	59***	46***	54***	53***	-43***
	(4.1)	(2.5)	(10)	(14)	(5.2)	(7.3)	(5.6)	(3.3)	(9.3)
Firm f.e.	Y	Y	Y	Y	Y	Y	Y	Y	N
N	2339	1927	1180	1646	1646	825	1055	1283	1250
R^2	.48	.5	.16	.5	.5	.52	.5	.49	.16

Note: This table reports regression estimates of the effect of the fuel economy standards on model torque (Equation 3). Sales volume is the number of units sold of that model-year vehicle. Except for columns II and III, only models with at least 1,000 units sold are included. Except for columns VI-VIII, a bandwidth of three years around 2009 policy is used. In columns VI-VIII, a bandwidth of three years around the specified year is used. Column IX does not include firm fixed effects as they are collinear with the Domestic indicator. $Domestic_j$ is 1 if the brand is domestic (Chinese), and 0 if foreign. $Policy_t$ is 1 if the year is 2009 or later, and 0 if 2008 or before. The unit of observation is the model-year. Except for regressions IV and V, standard errors are robust and clustered by firm. See Appendix A for a wide variety of additional tests, and all these tests using other dependent variables. *** indicates $p < .01$.

Table 9: Key Robustness Tests of Difference-in-Difference Estimation of the Fuel Economy Standard's Impact on New Vehicle Torque Part 2

Dependent Variable: Torque (nm)							
Test:	I. No individual effects	II. No interaction	III. No f.e.	IV. Year and firm f.e.	V. Year f.e.	VI. Class f.e.	VII. OEM f.e.
$\text{Policy}_t \cdot \text{Domestic}_j$	**-40*** **		**-20*** **	**-17*** **	**-20*** **	**-15** **	**-16*** **
	(7.2)		(6.2)	(5.3)	(6.2)	(5.8)	(5.6)
Policy_t		4	11***	15***	15**	9.4**	11**
		(3.5)	(4.1)	(5.5)	(6)	(3.8)	(4)
Domestic_j		-44***	-32***	58***	-32***	-38***	-25**
		(9.1)	(9.9)	(2.9)	(9.9)	(8.7)	(9.6)
$\mathbf{1}\ \vert \text{Minivan}_i$						51***	
						(12)	
$\mathbf{1}\ \vert \text{SUV}_i$						82***	
						(14)	
$\mathbf{1}\ \vert \text{Sedan}_i$						47***	
						(8.1)	
Firm f.e.	N	N	N	Y	N	Y	N
Year f.e.	N	N	N	Y	Y	N	N
OEM f.e.	N	N	N	N	N	N	Y
N	1646	1646	1646	1646	1646	1646	1646
R^2	.084	.13	.14	.5	.14	.23	.42

Note: This table reports regression estimates of the effect of the 2009 fuel economy standards on model torque, with a bandwidth of three years around 2009 policy (Equation 3). In column VI, there are fixed effects whether the vehicle class is Compact, Minivan, SUV and Sedan (Compact is omitted). In column VII, OEM refers to Original Equipment Manufacturer. Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. Policy_t is 1 if the year is 2009 or later, and 0 if 2008 or before. The unit of observation is the model-year. Standard errors are robust and clustered by firm, except in column VII, where they are clustered at the OEM level. See Appendix A for a wide variety of additional tests, and all these tests using other dependent variables. *** indicates $p < .01$.

Table 10: Domestic Firm Ownership Matrix

	Firm (brand) level		
	SOE	Privately owned	**Total**
Firms with JV	37	3	**40**
Firms without JV	6	22	**28**
Total	**43**	**25**	

	OEM level		
	SOE	Privately owned	**Total**
Firms with JV	20	2	**22**
Firms without JV	5	20	**25**
Total	**25**	**22**	

Note: This table shows the number of unique firms and OEMs that fall into various categories: being a locally or centrally state owned enterprise (SOE), being privately owned, having a joint venture (JV) with a foreign firm, and not having a JV. Note that many firms classified as SOEs are only majority held by the state and are partially privately owned and even publicly listed.

Table 11: Difference-in-Difference Estimation of the Fuel Economy Standard's Impact in Firm Type Subsamples

Dependent Variable:	I. Torque (nm)			II. Price (nominal dollars)		
Domestic sample:	a. All Firms w/ JV	b. SOEs w/JVs	c. Privately owned w/JVs	a. All Firms w/ JV	b. SOEs w/JVs	c. Privately owned w/JVs
Policy$_t$·Domestic$_j^{JV}$	**-22****	**-20***	**-31*****	**-3458*****	**-3378****	**-3750*****
	(8.9)	(10)	(11)	(1290)	(1430)	(941)
Policy$_t$	11**	11**	11**	3109***	3109***	3109***
	(4.2)	(4.2)	(4.2)	(905)	(905)	(913)
Domestic$_j^{JV}$	-34***	-39***	-14	-10996***	-11577***	-8551***
	(12)	(13)	(9.2)	(2492)	(2582)	(2179)
N	1295	1242	1068	1303	1251	1081
R^2	.11	.11	.023	.12	.11	.028
Dependent Var:	III. Torque (nm)			IV. Price (nominal dollars)		
Domestic sample:	a. All SOEs	b. SOEs w/o JVs	c. SOEs w/ JVs	a. All SOEs	b. SOEs w/o JVs	c. SOEs w/ JVs
Policy$_t$·Domestic$_j^{SOE}$	**-16****	**-10**	**-20***	**-3144*****	**-2791****	**-3378****
	(6.8)	(9.4)	(10)	(1131)	(1193)	(1430)
Policy$_t$	11**	11**	11**	3109***	3109***	3109***
	(4.2)	(4.2)	(4.2)	(904)	(911)	(905)
Domestic$_j^{SOE}$	-41***	-44***	-39***	-11968***	-12580***	-11577***
	(10)	(11)	(13)	(2359)	(2367)	(2582)
N	1381	1154	1242	1388	1166	1251
R^2	.14	.08	.11	.15	.086	.11
Dependent Var:	V. Torque (nm)			VI. Price (nominal dollars)		
Domestic sample:	a. All privately owned	b. Privately owned w/o JV	c. Privately owned w/ JV	a. All privately owned	b. Privately owned w/o JV	c. Privately owned w/ JV
Policy$_t$·Domestic$_j^{Priv.}$	**-21****	**-18***	**-31*****	**-2773****	**-2586***	**-3750*****
	(8.7)	(10)	(11)	(1351)	(1492)	(941)
Policy$_t$	11**	11**	11**	3109***	3109***	3109***
	(4.2)	(4.2)	(4.2)	(907)	(908)	(913)
Domestic$_j^{Priv.}$	-23*	-25	-14	-11442***	-12112***	-8551***
	(13)	(15)	(9.2)	(2520)	(2595)	(2179)
N	1280	1227	1068	1294	1242	1081
R^2	.066	.058	.023	.12	.11	.028

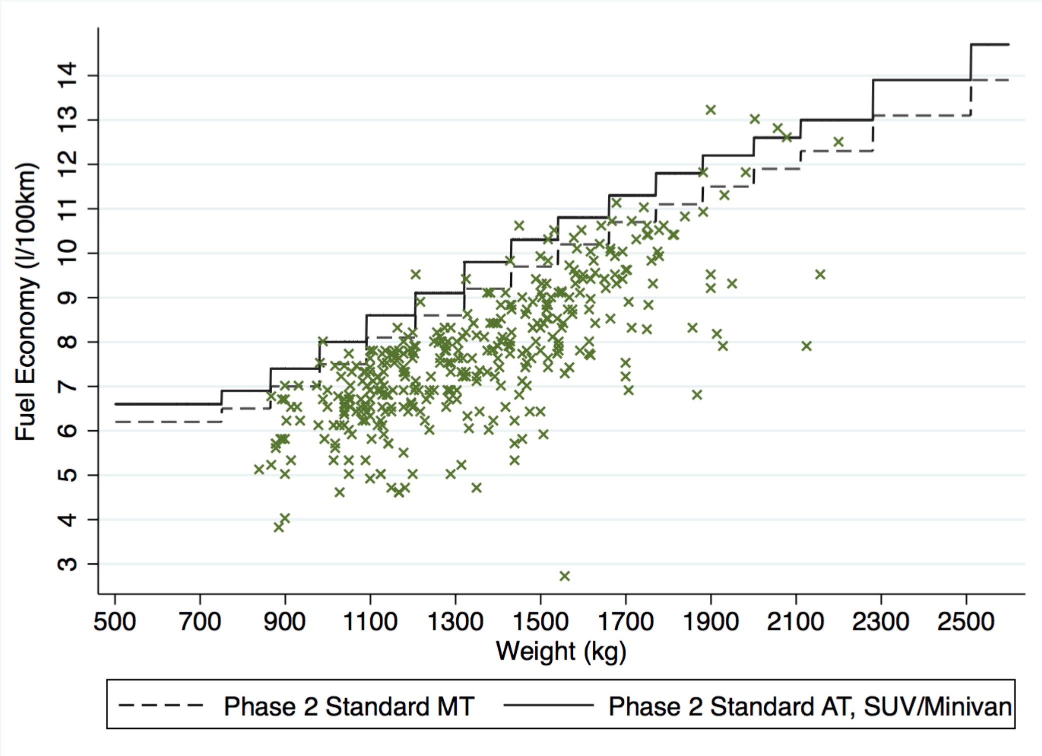
Note: This table reports regression estimates of the effect of the fuel economy standards on model torque and price, using a bandwidth of 3 years around the policy (Equation 3). Only certain subsets of domestic firms are used, as described in each specification. For example, I.a. compares domestic firms with joint ventures (JVs) with foreign firms, before and after the policy (domestic firms without JVs excluded). Only models with at least 1,000 units sold are included. Domestic$_j$ is 1 if the brand is domestic (Chinese), and 0 if foreign. Policy$_t$ is 1 if the year is 2009 or later, and 0 if 2008 or before. The unit of observation is the model-year. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 12: Difference-in-Difference Estimation of the Fuel Economy Standard's Impact on Firm Type Subsamples in Single Regression

Dependent Variable:	Torque (nm)			Price (nominal dollars)		
	I.	II.	III.	IV.	V.	VI.
Policy·Domestic^{JV}	**-24*****		**-24*****	**-3557*****		**-3554*****
	(7.9)		(8)	(848)		(848)
Policy·Domestic$^{\text{no JV}}$	**-12***			**-2223****		
	(6.4)			(903)		
Policy·Domestic^{SOE}		**-20*****			**-3473*****	
		(6)			(802)	
Policy·Domestic^{Private}		**-13***			**-1951****	
		(7.8)			(964)	
Policy·Domestic$^{\text{SOE no JV}}$			**-18*****			**-3364*****
			(4.4)			(1011)
Policy·Domestic$^{\text{Priv. no JV}}$			**-8.6**			**-1568**
			(8.6)			(1044)
Policy	11***	11***	11***	2858***	2858***	2858***
	(3.5)	(3.5)	(3.5)	(630)	(630)	(631)
Domestic^{JV}	59***		59***	4508***		4508***
	(2.7)		(2.7)	(490)		(490)
Domestic$^{\text{no JV}}$	53***			4579***		
	(7.3)			(862)		
Domestic^{SOE}		59***			4508***	
		(2.7)			(490)	
Domestic^{Private}		54***			6258***	
		(5.6)			(697)	
Domestic$^{\text{SOE no JV}}$			54***			4204***
			(7.2)			(722)
Domestic$^{\text{Priv. no JV}}$			50***			6177***
			(7.6)			(750)
Firm f.e.	Y	Y	Y	Y	Y	Y
N	1646	1646	1646	1653	1653	1653
R^2	.5	.5	.5	.63	.63	.63

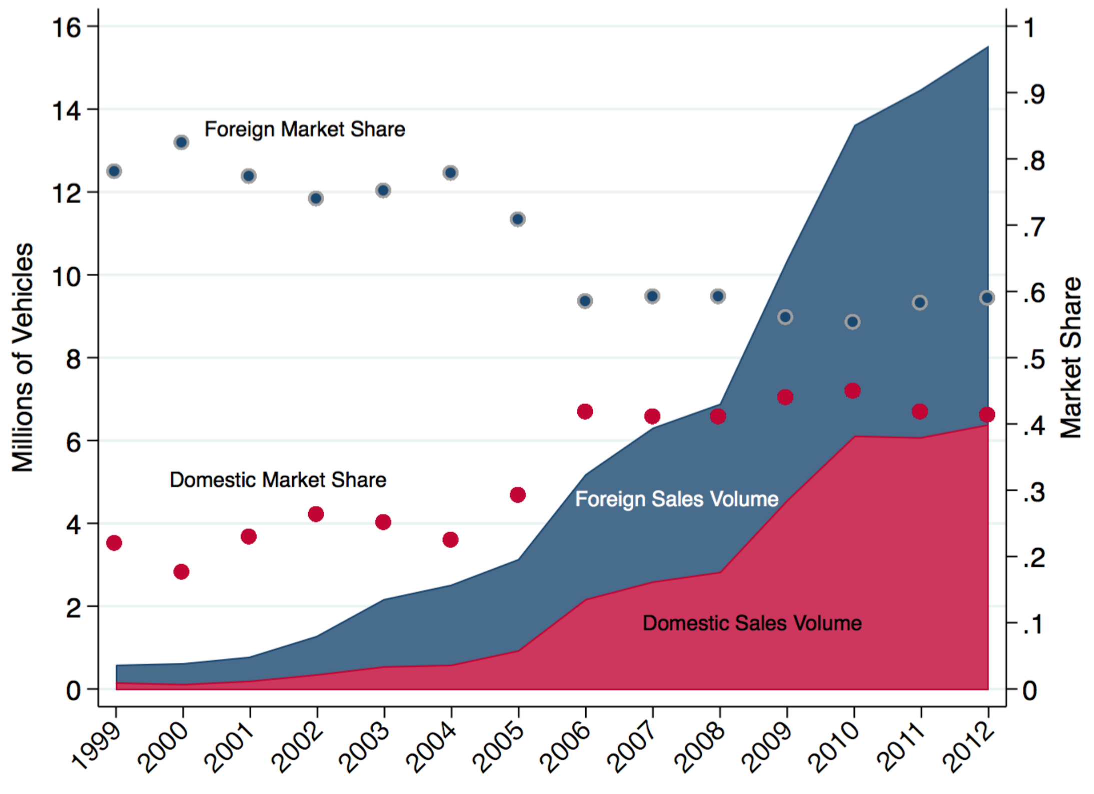
Note: This table reports regression estimates of the effect of the fuel economy standards on model torque and price, using a bandwidth of 3 years around the policy (Equation 3). Only models with at least 1,000 units sold are included. Domestic$_j^X$ is 1 if the brand is domestic (Chinese), and 0 if foreign, and fits into the category X (e.g. not being a SOE). Policy$_t$ is 1 if the year is 2009 or later, and 0 if 2008 or before. The unit of observation is the model-year. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Figure 1: Model Fuel Economy and Weight, with Phase 2 Standards, 2010



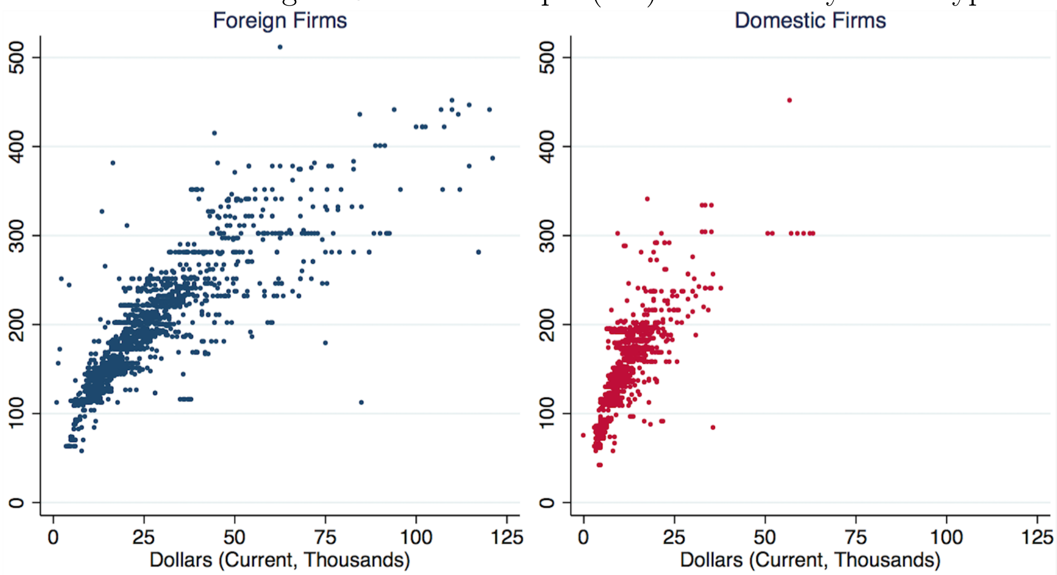
Note: This figure shows China's weight-based Phase 2 fuel economy standards, which were imposed in 2008 and 2009. The dotted line indicates the standard for manual transmission vehicles, while the line indicates the standard for automatic transmission vehicles and all SUVs and minivans.

Figure 2: Sales Volume and Market Share by Firm Type



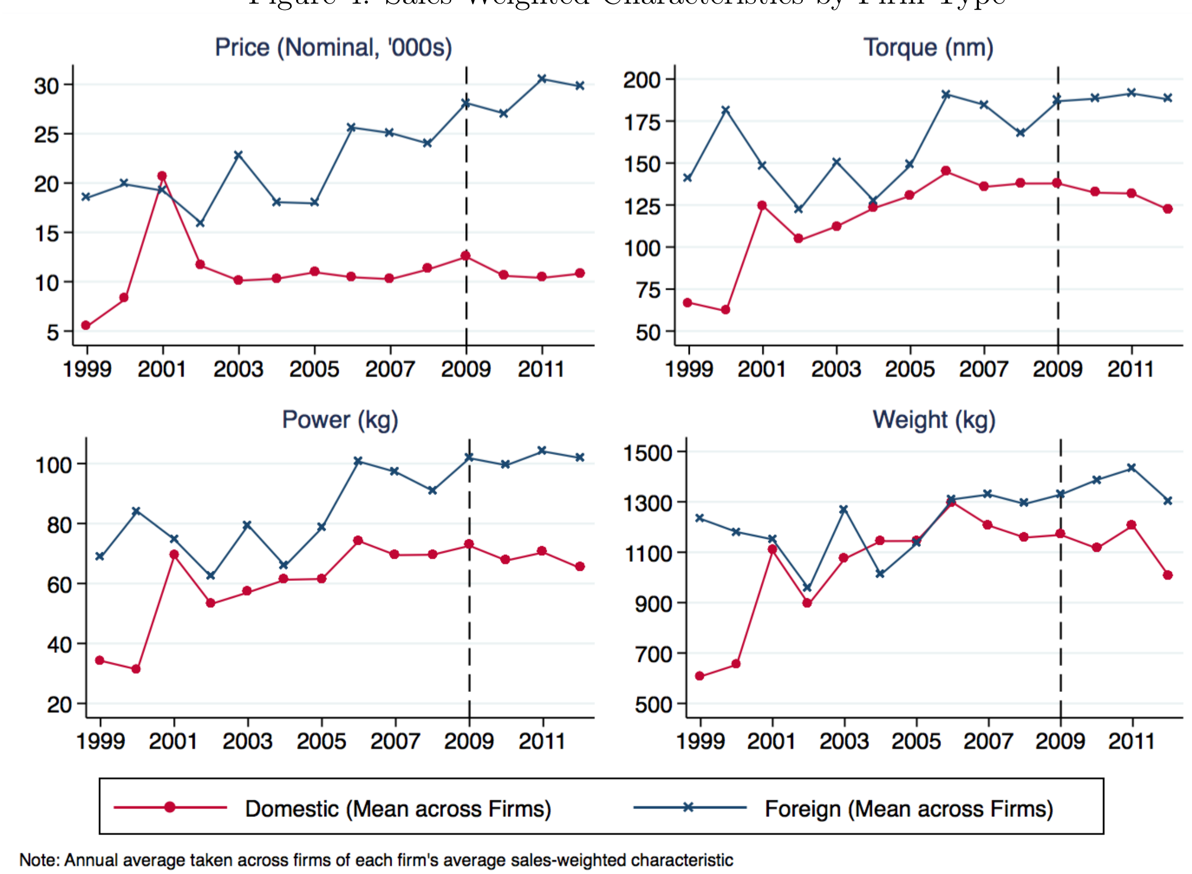
Note: This figure shows foreign and domestic brand Chinese sales volume (number of new vehicles sold in a given year) on the left axis, where the blue area is foreign and the red area is domestic. Market share of sales volume is on the right axis and in the foreign (blue) and domestic (red) scatterplot.

Figure 3: Model Torque (nm) and Price by Firm Type



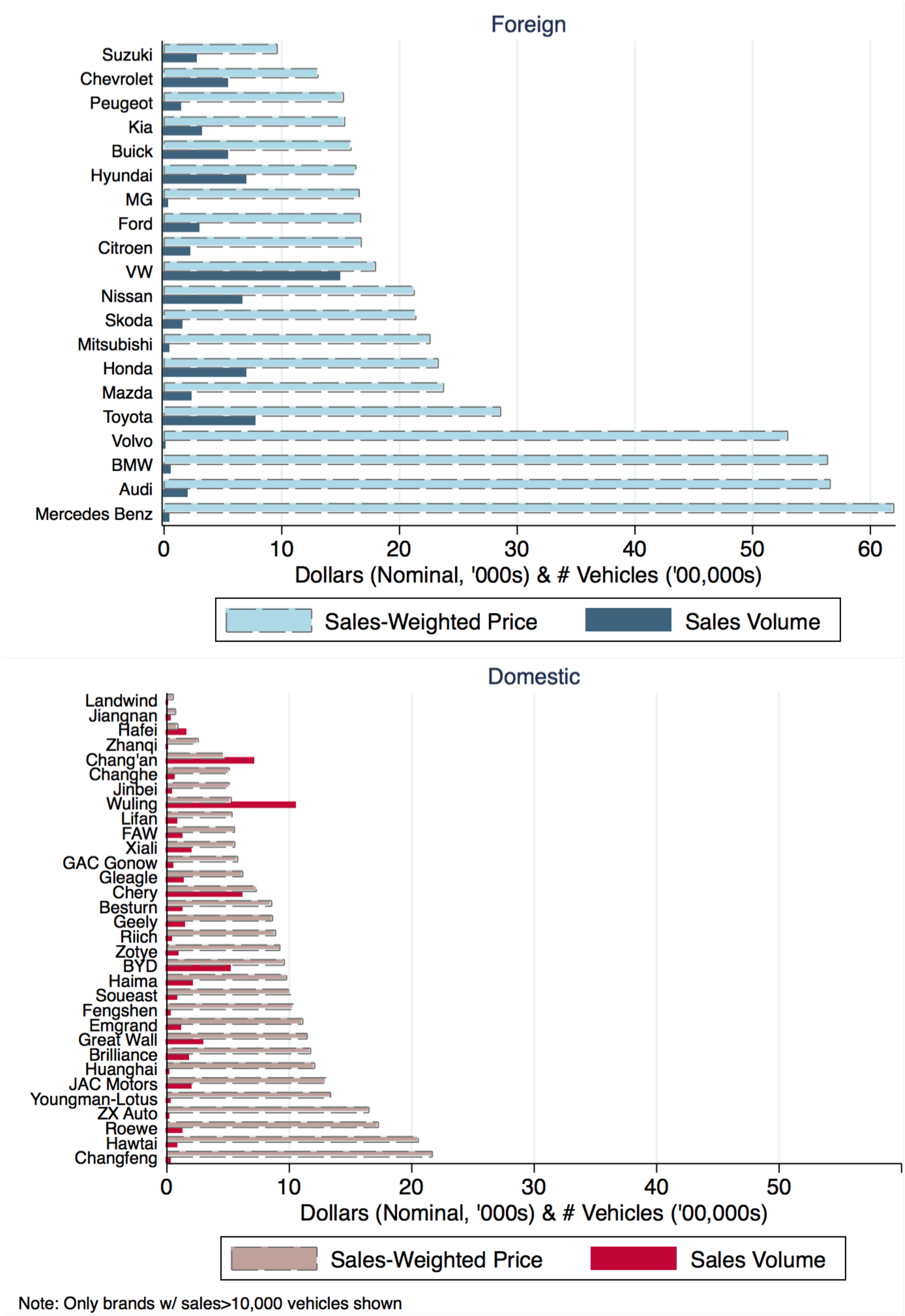
Note: This figure shows model torque (y-axis) and price (x-axis) for foreign firms and domestic firms. Each observation is a model-year, and all models sold between 1999 and 2012 are included.

Figure 4: Sales-Weighted Characteristics by Firm Type



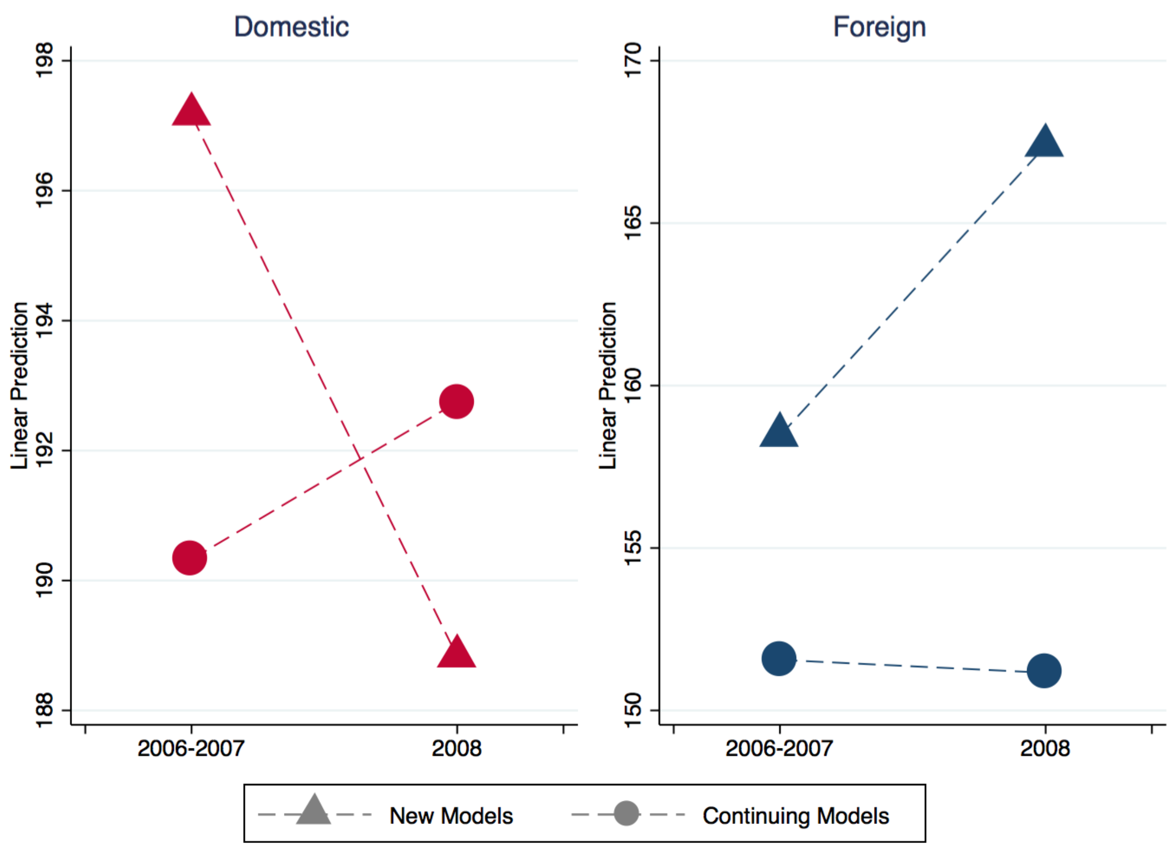
Note: This figure shows foreign (blue) and domestic (red) sales-weighted characteristics. The annual means are calculated by averaging across firms each firm's average sales weighted characteristic.

Figure 5: Firm-Specific Sales Volume and Sales-Weighted Price, 2010



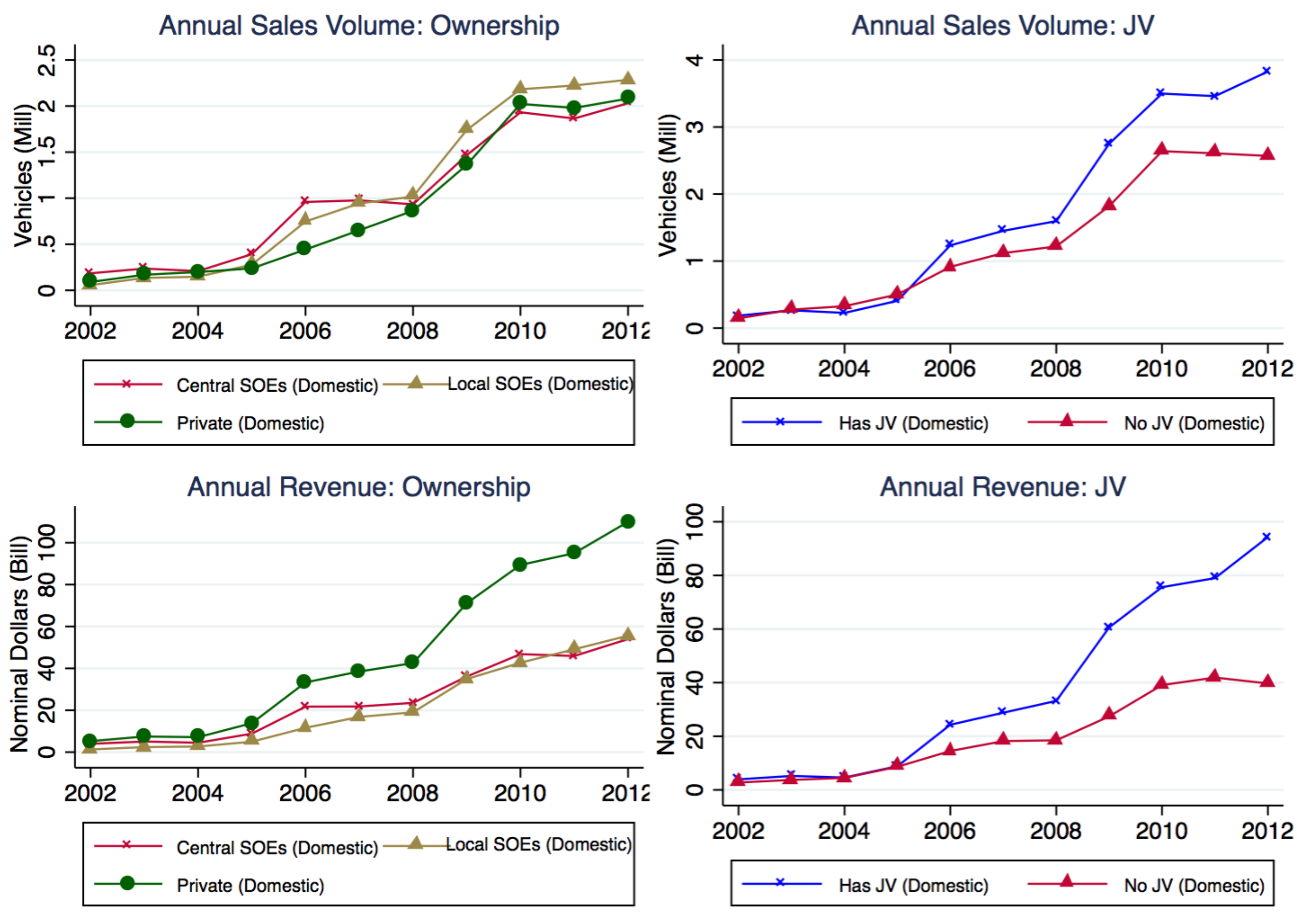
Note: This figure shows firm sales volume (number of vehicles) and sales-weighted average price across models sold for foreign firms (top graph) and domestic firms (bottom graph). Only data from 2010 is included.

Figure 6: Triple Difference Results for Torque: Predictive Margins by Firm and Model Type



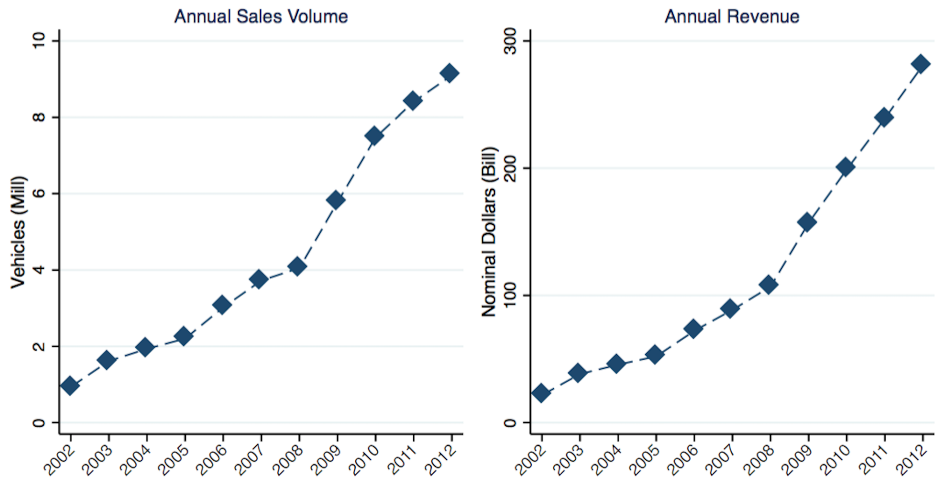
Note: This figure shows the predictive margins of the 2008 policy for new models, where torque is the dependent variable. In the left graph, the triangles hold fixed Domestic_j at 1 and Continuing_i at 0, and show how torque declined for new domestic models in 2008 relative to before the policy, in 2006-07. The policy did not apply to continuing models, and the circles show that domestic firms increased torque of continuing models slightly. Similarly, the blue triangles in the right graph show that foreign firms increased torque of new models while keeping that of continuing models roughly constant.

Figure 7: Total Sales Volume & Revenue among Domestic Firms by Ownership and JV Status



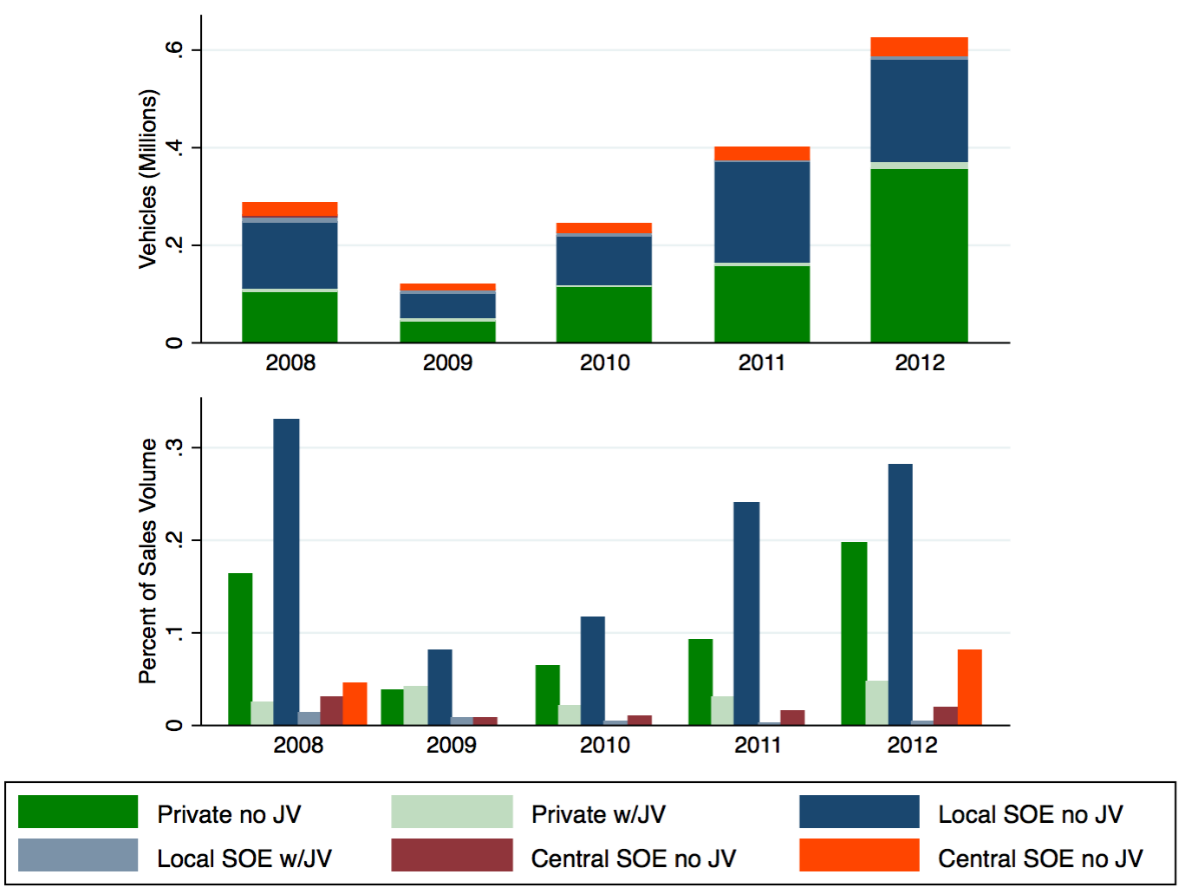
Note: This figure shows annual sales volume in the top two graphs, and annual revenue in the bottom two graphs. Only domestic (Chinese) firms are included. All graphs sum the number of vehicles or dollars across all firms in the category. The left two graphs divide the firms by ownership type, where Central State Owned Enterprises (SOEs) are owned by China's central government and local SOEs are owned by provincial governments. The right two graphs divide the firms by whether they have a joint venture (JV) with a foreign firm or not.

Figure 8: Total Sales Volume and Estimated Revenue among Foreign Firms



Note: This figure shows annual sales volume and revenue for foreign firms' sales in China. Note that all foreign firm production occurs in JVs with Chinese firms, but there is no overlap with Figure 7 because the Chinese firms produce own-branded models (shown in Figure 7), while the JVs themselves produce, typically, the foreign brand models.

Figure 9: Domestic Firm Export Volume and Percent of Total Sales Volume 2008-2012



Note: This figure shows Chinese domestic firm vehicle exports (there are essentially no foreign firm exports from China). The top graph shows the annual number of vehicles exported by ownership type, and the bottom graph shows this number as a share of the firms' total sales volume. For example, the first green bar in the bottom graph shows the total number of vehicle exports divided by the total number of vehicles sold among all firms who are privately owned and do not have a joint venture (JV).

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