Joint Ventures and Technology Adoption

A Chinese Industrial Policy that Backfired

Sabrina T. Howell*

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Abstract

Despite a rich theoretical literature, there is little causal evidence about the effectiveness of industrial policy. One common policy requires foreign entrants to form joint ventures (JVs) with domestic firms. China's auto sector is a useful case study, and recent fuel economy standards provide exogenous variation in the cost of acquiring technology. The standards led Chinese firms, especially those with JVs, to decrease quality relative to foreign firms rather than invest in fuel efficiency technology. Knowledge spillovers in JVs may not compensate for the negative impact of cannibalization incentives on innovation.

*New York University Stern School of Business. Email: sabrina.howell@nyu.edu. I am grateful to Anthony Saich and Henry Lee of Harvard, and Wang Qing and Lu Mai of the China State Council Development Research Center (DRC) for their support. I thank Martin Rotemberg for extensive, thoughtful suggestions, and also thank Lee Branstetter, Ariel Pakes, Paul Romer, and Lilei Xu for their help. Funding for this project is from the Belfer Center for Science and International Affairs at the Harvard Kennedy School and from a NSF Graduate Research Fellowship.

"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 private Chinese automaker (Ying 2012)

1 Introduction

This paper explores how industrial policies designed to induce technology transfer can backfire, perversely disincentivizing technology acquisition. Crucial to economic growth, technology transfer requires the recipient firm to invest regardless of the more advanced firm's posture. This investment can take many forms, such as imitating, stealing, licensing, or learning through joint work. Developing countries have frequently sought to hasten technology transfer by encouraging joint ventures (JVs) between foreign and domestic firms. In theory, a JV reduces the cost of technology acquisition by giving the domestic partner access to foreign R&D and manufacturing processes.

I focus on China's automotive industrial policy, which has called for globally competitive, high quality Chinese firms since the late 1970s.[1] A JV mandate for foreign entry is central to this policy: Foreign firms may produce and sell cars in China only through JVs with domestic firms. High tariffs preclude large-scale imports. For example, BMW manufactures in China solely through its JV with Brilliance Auto, a privately owned Chinese firm. Their JV plants produce only BMW vehicles. Brilliance helps finance the JV plant and receives fifty percent of profits from sales of China-manufactured BMWs. Brilliance also produces its own brands at other plants, where BMW is not involved.

I show that new fuel economy standards, which demand more advanced technology for high quality vehicles, led domestic firms like Brilliance to reduce quality and price while foreign firms like BMW continued on an upward trajectory. The down-market decision may or may not have been profit maximizing. Regardless, it contrasts with the government's

[1] See, for example, State Council (1994, 2006).

desire for Chinese brands with high quality engineering.

Foreign brands like Volkswagen, GM, and Toyota consistently dominate the local market, particularly in the more profitable, higher priced segments. The failure of China's auto industrial policy is an interesting puzzle that goes beyond the inefficiencies associated with state ownership of some automakers (see Hsieh and Song 2015). Evaluating the effect of having a JV on domestic firm innovation is challenging, yet this relationship is at the heart of China's auto industrial structure and is relevant not only in other Chinese sectors where foreign entrants are pressured to form JVs, but also in other developing countries that have mandated JVs, including Brazil, Mexico, India, Nigeria, and Malaysia.[2]

China's sudden and stringent 2009 fuel economy standards provide plausibly exogenous variation in the fixed cost of technology upgrading.[3] An automaker facing fuel economy standards can either implement fuel efficiency technologies or reduce quality by decreasing horsepower, torque (acceleration), and/or weight. The standards imposed a fixed cost disadvantage on domestic firms. Foreign firms, who already faced such standards elsewhere, incurred only the variable cost of including their efficiency technologies in local production.

With novel, reliable data, I show that after the standards, domestic firms reduced quality and price relative to foreign firms, and did not gain market share. I use comprehensive model-level sales and characteristics data for the Chinese auto market between 1999 and 2012 in a difference-in-differences (DD) design. Foreign firms are the control; I assume their technology transfer behavior was unchanged immediately around the standards. The DD analysis finds that the standards reduced domestic model price relative to foreign models by \$2,784, 13% of the mean, torque by 12% of the mean, horsepower by 8% of the mean, weight by 4% of the mean, and length by 2% of the mean. Foreign firms continued on their prior path.

A second empirical approach exploits the standards' staged implementation. New

[2]See UNCTAD 2003, Mathews 2002, and Blomström et al. 2000.

[3]China imposed fuel economy standards in phases from 2005-2009, but binding standards came into force in 2009 (see Section 4).

and continuing vehicle models faced the standards in 2008 and 2009, respectively.[4] The triple-difference design confirms the main result. In 2008, domestic firms' continuing models were more powerful, more expensive, and heavier than new models already subject to the policy, relative to the same comparison within foreign firms. Both designs use within-firm variation. I conduct a rich array of robustness tests, including placebos with other years, various bandwidths around the policy, different fixed effects, and alternative assumptions about standard errors.

I disaggregate the standards' impact along two dimensions: whether the firm has a JV, and whether it is a state-owned enterprise (SOE). Few firms are SOEs without a JV or private with a JV, so the exercise suffers from a small sample problem. I can disentangle the JV and state ownership effects for only some characteristics. With this caveat in mind, I conclude that among SOEs, the negative effect of having a JV appears stronger than that of being state owned. Privately owned firms without JVs reduced quality and price the least in response to the standards. These results are consistent with the literature documenting that (a) private firms are more productive than SOEs in China; and (b) there is a a negative correlation between JVs and technology diffusion.[5]

My findings may simply reflect state ownership. However, an alternative is that the JVs generated large rents but reduced domestic firm innovation incentives. In a stylized model, I show how the domestic partner in a JV is disincentivized from producing substitutes to the foreign partner's models to avoid cannibalizing its share of foreign brand profits. The negative effect of increasing own quality on the share of JV profits might outweigh any advantage from knowledge spillovers. The spillover benefits of JVs are the focus of previous theoretical literature, such as Müller and Schnitzer (2006). The cannibalization channel that I propose may be at play among JVs more broadly, regardless of whether they are established

[4]For example, the 2008 Great Wall Peri was a new model as it was not produced in 2007, while the 2008 Volkswagen Jetta was a continuing model.

[5]On (a), see Chen et al. 2015, Hsieh and Klenow 2009, Fang and Lerner 2015, Allen et al. 2005, Khandelwal et al. 2012, and Lin et al. 1998. On (b), see Ramachandran 1993, Moran 2002, Blomström et al. 1992, and Urata and Kawai 2000. However, other studies find evidence of positive spillovers, like Javorcik (2004) and Dimelis and Louri (2002).

voluntarily or whether the partner firms have similar technical capacity.

Technology diffusion is central to economic development (Lucas 1993, Young 1991). A story in which JVs lead domestic firms to move *down* the manufacturing quality ladder helps to reconcile FDI's positive role in the endogenous growth literature with mixed empirical findings at the country level, where industrial policy often regulates FDI.[6] More broadly, my results speak to a fundamental debate about post-World War II growth. New growth theory advocates trade and investment openness to close technology gaps (Coe and Helpman 1995, Baldwin 1969). Others contend that institutions are paramount and attribute the success of East Asian "Tigers" to government direction (Rodrik et al. 2004, Amsden 1989). Despite a rich theoretical literature, there is little strong empirical evidence of the effectiveness of industrial policies that target technology upgrading.[7] An exception is Rotemberg (2015), who assesses the causal impact of industrial policy changes on firm productivity.

China could have pursued alternatives to the JV mandate. One option is to liberalize foreign firm entry and imports. The electronics sector, where China placed fewer constraints on FDI and permitted freer competition, illustrates the potential for rapid growth and dynamic indigenous firms like Xiaomi and Lenovo. A second path, albeit more difficult under contemporary trade law, is Japan and Korea's infant industry protection combined with foreign technology licensing and reverse engineering.

To my knowledge, this paper is the first quasi-experimental evaluation of an industrial policy's effect on firm technology acquisition in a developing country. I depart from much of the past literature by using product technical quality, rather than production functions and accounting-based productivity measures. Firm-level panel data is also relatively rare in

[6]On industrial policy broadly, see Grossman and Helpman (1994), Nunn and Trefler (2010), Mingo and Khanna (2013), and Arnold and Javorcik (2009). Borensztein et al. (1998), Haskel et al. (2007), and Blalock and Gertler (2007) find that FDI positively affects productivity, while Carcovik and Levine (2005), Haddad and Harrison (1993), Konings (2001), and Aitken and Harrison (1999) find that it does not. See Hale and Long (2011 and 2012) for a review. The small literature on JVs finds both positive effects (Lyles and Salk 1996 and Mathews 2002) and negative effects (Inkpen and Crossan 1995, Doner 1991, and Grieco 1984). The literature evaluating FDI in China has not addressed domestic partner learning (Du et al. 2011, Lin et al. 2009, Xu 2008).

[7]Key theoretical contributions include Bardhan 1971, Romer 1993, Melitz 2005, Pack and Saggi 2006, and Harrison and Rodríguez-Clare 2010.

the literature on technological capacity and innovation, which has relied on aggregates, case studies or cross-sectional survey data, particularly for the developing world (Fagerberg et al. 2010, Figueiredo 2006). In addition to contributing to the industrial policy debate, this paper relates to the literatures on innovation, FDI, the Chinese economy, and the impacts of energy efficiency regulation.

The paper proceeds as follows. I provide historical context about the Chinese auto sector in Section 2. Section 3 shows how JVs may affect innovation investment incentives. I describe the data and provide descriptive statistics about the industry in Section 4. The estimation strategy is proposed in Section 5, and Section 6 contains the main results.

2 Historical Industry Context

Since the late 1970s, China has vigorously deployed industrial policy in the service of building a globally competitive, high quality indigenous auto sector. 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.[8] 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). Yet Foreign brands dominate China's passenger vehicle market in terms of quality, price, and market share. Domestic firms' decision to produce low quality, low price models runs counter to explicit government directives.

Beijing permits FDI in vehicle production only via partnerships with domestic firms. Very high import tariffs historically made a JV the only way a foreign firm could access China's market.[9] The JV is a stand-alone enterprise producing only foreign brand cars

[8]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)

[9]Tariffs have been 180-220% through 1994, 70-150% through 2001, 30% through 2005, and 25% thereafter. Appendix A Figure 1 shows that less than 0.5 million vehicles were imported until 2010. Imports, primarily in the form of SUVs, have since risen to about 1 million. The protected environment enabled high markups.

(during the period studied here). The foreign partner owns no more than 50%, and usually also retains 50% of profits. The foreign firm designs, controls, and operates the plant. For example, BMW's China production occurs in a JV with Brilliance Auto, a domestic privately owned firm. The JV manufacturing plant produces only BMW models. The domestic partners were supposed to evolve into multinationals competing in foreign markets (State Council 2006). Initially, domestic partners were hand-picked by the government, but recently JVs have merely required government approval (Richet and Ruet 2008).

Early domestic partners were all state owned. Following WTO accession in 2001, the government gradually removed barriers to entry for private firms. Today domestic Chinese auto manufacturers can be divided along two dimensions: whether they are state-owned, and whether they have a JV with a foreign firm. State owned enterprises (SOEs) are majority owned by provincial governments (local SOEs) or the central government (central SOEs). A primary focus of the literature on China's economy has been the inefficiency of SOEs relative to private firms.[10] However, in some high-tech sectors, such as shipping, SOEs have become globally competitive, dominating the domestic market and achieving meaningful exports (see Appendix B for discussion and evidence). 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.

Foreign firms benefited in contract negotiation 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). For example, GM aggressively marketed itself as a purveyor of useful technology, establishing a joint research center with its Chinese partner. But the research center was largely used to tweak existing GM-branded models for the Chinese market. Further, most GM-branded models initially chosen for China were Daewoo or Opel designs,

Deng and Ma (2010) estimate that between 1995 and 2001, Volkswagen had a 41% market share and markups of 42%.

[10] See Khandelwal et al. (2012), Bajona and Chu (2010), Jefferson et al. (2003), and Lin et al. (1998).

further distancing GM's China operation from Detroit's state-of-the-art (Tang 2012).

JVs initially used outdated technology, in part to bound potential technology transfer (Oliver et al 2009). Their behavior is consistent with Branstetter and Saggi (2011), who theorize that stronger intellectual property rights reduces imitation risk and thus increases FDI and subsequently incentives for innovation. In response, a 1994 policy directive 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).[11]

These policies were unenforceable, but greater market discipline led foreign firms to produce the latest models in China by the mid-2000s. Competition came from a number of fronts. First, SOEs were corporatized, largely separated from direct government control, and often partially listed on stock exchanges (Andrews-Speed 2012). Second, between 2000 and 2012, the number of foreign firms producing in China through JVs increased from 4 to 17, and the number of domestic firms with and without JVs increased from 2 to 11, and 1 to 17, respectively (see Appendix A Figure 3). Though China has been the world's largest passenger vehicle market since 2010, the economies of scale that characterize the global auto industry have thus far eluded Chinese firms. Domestic firm entry undermined government efforts to consolidate the industry (State Council 1994). Beijing calls for "self-reliant Chinese car manufacturers who rank among the 500 largest global firms" (NDRC 2004). Yet the industry press concludes: "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" (Yang 2009).

3 The Impact of Joint Ventures on Technology Adoption

Case studies and the popular press provide anecdotal evidence that (a) JVs failed to achieve technology transfer; and (b) domestic firms have not developed innovation and design capa-

[11] WTO terms forbid market access-technology transfer *quid pro quo*, but the stated technology transfer requirements remain in place.

bility.[12] For example, a 2012 Wall Street Journal article quoted former minister He Guangyan as saying the JVs are "like opium" for the domestic firms, and concluded 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" (Dunne 2012).

China sought to exchange market access for technology transfer from foreign firms. Yet dynamically the JV industry structure may have attenuated innovation incentives. Producing substitutes to its foreign partner's models cannibalizes the domestic firm's share of JV profits. Consider the following stylized profit functions for domestic firms:

$$\text{Firm without JV: } \pi_j = \sum_{i \in j} q_i(\mathbf{p}, \phi_i) \left(p_i - C_{i,\text{No } JV} \right) \tag{1}$$

$$\text{Firm with JV: } \pi_j = s\pi_{JV}^{foreign} + \sum_{i \in j} q_i(\mathbf{p}, \phi_i) \left(p_i - C_{i,JV} \right), \tag{2}$$

where j denotes firm, i denotes model, ϕ technology quality, and s the domestic firm's profit share from foreign model sales (typically 50%).

Fuel economy standards imply that the firm must acquire fuel efficiency technology in order to meet the standards and maintain quality (torque, power and weight). I assume ϕ increases with torque and horsepower, and the equilibrium vehicle price, p_i, increases with quality and also depends on all models in the market.[13] 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 the cost of acquiring fuel efficiency technology is additive such that $C_i = \mathcal{F}(\cdot, \phi_\text{i} + \text{F}_\text{j}(\phi_\text{i}) \mid \text{Weight}_\text{i})$.[14] The foreign firm already possesses the technology, so within its cost function $F_{foreign} = 0$. Firms with JVs may have greater access to foreign firm technology than firms without JVs, so $F_{j \in JV} \leq F_{j \in No\ JV}$.

[12] See Gallagher (2006), Holmes et al. (2013), Economist (2013), and Sanford C. Bernstein (2013).

[13] That is, $\frac{\partial \phi_i}{\partial \text{Torque}_i} > 0$; $\frac{\partial \phi_i}{\partial \text{Power}_i} > 0$; and $\frac{\partial p_i}{\partial \phi_i} > 0$.

[14] The key stylized fact is that the firm faces a fixed cost to acquiring technology, which then can be applied to any model. An implicit assumption that this fixed cost is spread equally across models and firms have equal numbers of models. It need not be additive.

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; $\frac{\partial C_{i,JV}}{\partial \phi_i} \leq \frac{\partial C_{i,No\ JV}}{\partial \phi_i}$.

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:

$$\begin{aligned} \text{Firm without JV: } \frac{\partial \pi_j}{\partial \phi_i} &= q_i(\mathbf{p},\phi_i)\left[\frac{\partial p_i}{\partial \phi_i} - \frac{\partial C_{i,No\ JV}}{\partial \phi_i}\right] \\ &\quad + \frac{\partial q_i(\mathbf{p},\phi_i)}{\partial \phi_i}(p_i - C_{i,No\ JV}) + \sum_{k \neq i \in j}\left[\frac{\partial q_k(\mathbf{p},\phi_k)}{\partial \phi_i}(p_k - C_{k,No\ JV})\right] \end{aligned} \tag{3}$$

$$\begin{aligned} \text{Firm with JV: } \frac{\partial \pi_j}{\partial \phi_i} &= s\frac{\partial \pi_{foreign,\ JV}}{\partial \phi_i} + q_i(\mathbf{p},\phi_i)\left[\frac{\partial p_i}{\partial \phi_i} - \frac{\partial C_{i,JV}}{\partial \phi_i}\right] \\ &\quad + \frac{\partial q_i(\mathbf{p},\phi_i)}{\partial \phi_i}(p_i - C_{i,JV}) + \sum_{k \neq i \in j}\left[\frac{\partial q_k(\mathbf{p},\phi_k)}{\partial \phi_i}(p_k - C_{k,JV})\right] \end{aligned} \tag{4}$$

The foreign firm's profit decreases in a competitor's quality $\left(\frac{\partial \pi_{foreign,\ JV}}{\partial \phi_i} < 0\right)$. Thus the domestic firm's investment in own quality reduces its marginal profit from the JV.[15]

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:

$$\phi_{i,JV} > \phi_{i,No\ JV} \text{ if } s\left[\frac{\partial \pi_{foreign,\ JV}}{\partial \phi_i}\right] - \frac{\partial C_{i,JV}}{\partial \phi_i} > -\frac{\partial C_{i,,No\ JV}}{\partial \phi_i} \tag{5}$$

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 empirical analysis, I test whether $\phi_{i,JV} > \phi_{i,No\ JV}$ or vice versa.

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

4 The Data and Source of Exogenous Variation

This section first introduces the data and explains the units of analysis. I then present descriptives statistics. Last, Section 4.3 describes the fuel economy standards.

Units of Analysis

This paper is based on novel, comprehensive, model-level data of light-duty passenger vehicle sales in China between 1999 and 2012. The data is from the State Council Development Research Center, which is the policy analysis organization for China's top-level State (i.e. not Party) governing apparatus. The data is quite reliable, as it originates in police registration data.[16] Each observation is a model-year, and includes - in Chinese - the ultimate Original Equipment Manufacturer (OEM), brand, model name, vehicle class, engine displacement, and power train.[17] I acquired the following model-year characteristics through web scraping: price (MSRP), maximum torque (nm), peak power (kw), curb weight (kg), length (mm), height (mm), and fuel economy (l/100 km).[18] I convert price into dollars using the average monthly exchange rate that year, and all price figures are nominal.

Vehicle torque, responsible for acceleration and power, is a useful measure of vehicle quality.[19] Torque depends not only on the engine but also transmission ratios, weight, and 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. Horsepower is the amount of energy the engine can

[16]Consumers (private and public) must register new vehicle purchases to the local police. 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.

[17]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.

[18]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.

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

produce and determines the top speed of the vehicle.[20] 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 SAIC subsidiary. 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 level, especially in China, where some OEMs are JVs producing domestic and foreign brand vehicles, albeit at different plants. I show that my empirical results are robust to grouping at the OEM level.

Descriptive Statistics

Summary statistics of the firms and model characteristics are in Tables 1 and 2, respectively. The first three columns divide the sample into three periods, two prior to the fuel economy standards (1999-2004 and 2005-2008) and one after (2009-2012). Table 1 shows that the number of domestic firms nearly doubled over the course of the data, with most entry 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 prices in nominal dollars have stayed essentially constant, while foreign prices have increased significantly. The overall average foreign firm sales-weighted mean price is \$24,200, while for domestic firms it is \$10,800. Table 2 takes the

[20]Horsepower is torque multiplied by a given speed (usually in rpm). Its correlation with price is 0.84, and with torque 0.9.

model-year is the unit of observation and does not weight characteristics by sales. Domestic Chinese model torque, power and weight increased between the first and second periods, but decreased or remained stable in the periods bracketing the fuel economy policy. Among foreign firms, all six characteristic means increase each period. However, due to high variation in within-group characteristics, no differences are statistically significant.[21]

I estimate the relationship of characteristics to vehicle price as follows:

$$Y_{it} = \alpha + \beta_1 \text{Domestic}_j + \beta_2 \text{Torque}_i + \beta_3 \text{Weight}_i + \beta_2 \text{Height}_i + \beta_2 \text{Length}_i + \delta' \mathbf{1} \mid \text{Class}_i + \varepsilon_{ijt}, \quad (6)$$

where j denotes firm and i denotes model. The results in Table 3 confirm a large 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. 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 discount for SUVs relative to compact cars (the omitted class dummy), but there is no measurable relationship between the other classes and price. The disproportionate increase in SUV sales among domestic firms relative to foreign firms may explain this feature (Appendix A Figure 4).

JVs are not exogenously assigned, making it difficult to disentangle the effects of state ownership and JV status. Table 1 Panel D shows that 37 of the 43 SOEs have a JV. Of the 25 privately owned firms, only 3 have a JV. My estimation relies on the small number of SOEs without JVs and private firms with JVs. During the period studied, domestic private firms had better sales and revenue growth than state-owned firms, but there was no obvious difference between JV and non-JV domestic firms (Table 1 Panel B).

Figure 1 shows 2010 sales and price figures for all foreign (top) and domestic (bottom) firms with sales of at least 10,000 vehicles. There are twice as many such domestic firms, and

[21]See Appendix A Table 1 for summary statistics by ownership and JV status within domestic firms.

their sales-weighted prices are dramatically lower.[22] Figure 2 compares foreign and domestic market share; the latter has hovered at about 40% since 2006. It also shows overall sales, which increased from just 0.6 million vehicles in 1999 to nearly 16 million in 2012. Variety increased as well; the number of models increased fairly linearly from 23 in 1999 to 426 in 2012.[23] In the 2004-2006 period, domestic firms gained substantial market share.

The strong relationship between torque and price and their marked difference across foreign and domestic firms are in Figure 3. Figure 4 shows the evolution of sales-weighted price and torque averaged across firms and then across firm types.[24] Since 2009, domestic firm torque has decreased relative to foreign firms (top left), and within domestic firms it has decreased among firms with JVs relative to firms without JVs (bottom left). Figure 5 shows a scatterplot of model torque with fitted polynomials by firm type. In the left graph, the large decline of domestic firm torque after the standards, while foreign firm torque continued on its prior path, is quite evident. The right graph compares domestic firms with and without JVs.

Empirically, exporting is strongly associated with firm productivity and competitiveness.[25] Chinese central government policy also explicitly targets auto exports (State Council 2009). Total exports remained small in 2012, at 0.6 million vehicles compared to domestic consumption of about 16 million. Although exports are increasing, they remain far from meeting the government targets (Roland Berger 2013). Since 2008, private firms and local SOEs without JVs have been responsible for almost all passenger vehicle exports, depicted in Figure 6.[26] Between 2008 and 2012, private firms without JVs exported 10-20% of their

[22] The same graphs at the OEM level are in Appendix A Figure 5.

[23] Versions of the same model with different engine sizes are not treated as different models.

[24] 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). Appendix A Figures 6 and 7 show sales volume and revenue by ownership and JV status.

[25] See Clerides, Lach and Tybout (1998), Melitz and Redding (2014), Giles and Williams (2000), and Wakelin (1998).

[26] 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

total sales, and local SOEs without JVs exported 10-30%, though essentially none of these exports were to developed countries. Several high profile Western crash test outcomes help explain the lack of developed country demand. For example, in 2007 Germany and Russia tested Chinese sedans made by Brilliance Jinbei and Chery, respectively. German officials described the Brilliance crash test as "catastrophic," while the Russian evaluators described the Chery performance as among the worst they had ever encountered (Osborn 2007).

The Fuel Economy Standards and Vehicle Quality

In 2004, China's National Development and Reform Commission announced that China would adopt fuel economy standards, with 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).

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.[27] Heavier and more powerful vehicles generally have higher profit margins than other segments (IMF 2006).

Multinational automakers have faced stringent fuel economy standards in Japan and Europe for decades, and have developed technologies permitting heavy, powerful cars to meet those standards. Knittel (2011) examines the trade-offs in the U.S. auto industry. He shows 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 dramatically improved fuel efficiency technology

(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, such as Chery.

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

between 1980 and 2006, but the progress served primarily to maintain fuel economy while increasing power and heft.[28]

China's fuel economy policy compelled foreign firms to insert technologies developed for other markets into their China production. This cost was largely variable as the same models are built and sold globally, generating the assumption in Section 3 that $F_{foreign} = 0$. Conversely, if domestic automakers wished to maintain existing models' torque, weight, and power, they had to acquire fuel efficiency technologies and integrate them into the model design ($F_j(\phi_i) > 0$). According to a Wall Street Journal article, "New proposed [2016] 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" (Battacharya 2014).

Beijing implemented Phase 1 fuel economy standards 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. The Phase 2 standards are graphed in Figure 8, and Appendix A Table 2 lists the standards by weight class.[29] Phase 2 is more stringent than current U.S. standards, but much less stringent than Japanese and European standards (Appendix A Figure 8 compares standards across countries). The Chinese standards are designed to be stricter for heavier vehicle classes (An et al. 2011).[30] Before the stan-

[28]Some fuel efficiency technologies - particularly in the engine - may be outsourced to suppliers. Foreign firms operating in China source 25-75% of their parts in China, but still import the most advanced parts (Takada 2013, Yang 2008). Component suppliers are an important part of the automotive industry. However, they are an independent sector and beyond the scope of this paper. To illustrate, branded automakers are in SIC code 3711 (Motor Vehicles and Passenger Car Bodies), whereas parts are in 3714 (Motor Vehicle Parts and Accessories). Parallel NAICS codes are 3361 and 3363. Engineering and design competency at the branded automaker level are required to integrate a new technology and effectively model its trade-offs; a passenger car's 15,000 parts must fit perfectly and function consistently to meet consumer expectations (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).

[29]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.

[30]In general, fuel economy standards generate an incentive to down-weight certain classes of vehicles, which has been shown to have negative social welfare effects because when the fleet has widely varying weight, crashes are more likely fatal for passengers in small cars (Jacobsen 2013, Anderson and Auffhammer 2014). 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. This generates the perverse incentive to meet standards either by increasing fuel economy within a class, potentially by

dards, automakers selling vehicles in China did not have to report fuel economy. However, a number of studies conclude that the initial 2006-07 standards were not binding.[31] Further, government inspection and enforcement were lax prior to the Phase 2 implementation. 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 was 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.[32] I use 2009 as the policy implementation year in my primary estimation. Figure 7 shows reported 2010 new vehicle fuel economy alongside the Phase 2 standards. Assuming accurate reporting, the vast majority of models met the standards.[33]

5 Empirical Strategy

In a difference-in-differences (DD) design, I compare foreign and domestic firms' model 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. Domestic firms' sudden fixed cost disadvantage in building higher quality vehicles is the "treatment."

decreasing weight, or by jumping to a higher weight class with a more lenient standard. Sallee and Ito (2013) find that Japan's weight-based standards impose large safety costs. 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).

[31] See Wagner et al. (2009), Oliver et al. (2009), and An et al. (2007).

[32] I met with Shi Jian and Liu Bin in the CATARC Auto Industry Policy Research Division.

[33] A Phase 3 program is currently underway that adds 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.

I demonstrate that foreign firms did not respond measurably to the policy; they are the "control" to the degree that the policy did not affect their vehicle quality because they already possessed fuel efficiency technology. However, since the policy applied to all firms, the estimated treatment effect is best interpreted as the difference in responses across firm types.

In practice DD estimators pose two potential problems. First, the design fails if the policy is endogenous to the group studied. The fuel economy standard affected both foreign and domestic firms, and I have not found other policies or market structure changes in the period analyzed that affected only domestic firm production. Further, since the policy aimed to hasten technology transfer, endogeneity should push the effect towards an improvement in domestic firm quality. Second, serial correlation in variables may cause downward bias in the standard errors, especially with a relatively long time series and DD implementation via time fixed effects. As in most DD designs, the dependent variables here 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.[34] 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 using all years and including year fixed effects yields roughly the same results. I also demonstrate that conventional firm-year clusters cause downward bias in standard errors.

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

$$Y_{it} = \alpha + \beta\left(\text{Policy}_t \cdot \text{Domestic}_j\right) + \gamma_1 \text{Policy}_t + \gamma_2 \text{Domestic}_j + \lambda_j + \varepsilon_{ijt}. \tag{7}$$

The outcome of interest is Y_{it}, such as 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

[34] See Bertrand, Duflo and Mullainathan (2004) and Donald and Lang (2007).

(such as BYD or Chery), and 0 if it is foreign (such as Nissan or GM). I include firm fixed effects λ_j to control for unobserved firm-specific variables related to characteristic choice. The coefficient of interest β is the effect of the policy on domestic firms relative to foreign firms.[35] The parallel trends assumption - that the error term is uncorrelated with the other variables - is not directly testable, but I present evident to support it in Section 4.2. The primary specification includes models with sales volume of at least 1,000 vehicles.

The second specification is a difference-in-difference-in-differences, or triple-difference, design, which is more robust than any DD approach (Imbens and Wooldridge 2007). This approach exploits the staged policy implementation, in which the standard applied only to new models in 2008, but to both new and continuing models in 2009. Automakers sensitive to the policy may have changed new model but not continuing model characteristics in 2008. The estimating equation is:

$$\begin{aligned} Y_{it} \;=\; & \alpha + \beta\left(\text{Policy}_t^{2008} \cdot \text{Domestic}_j \cdot \text{Continuing}_{it}\right) + \gamma_1\left(\text{Policy}_t^{2008} \cdot \text{Domestic}_j\right) \\ & + \gamma_2\left(\text{Policy}_t^{2008} \cdot \text{Continuing}_{it}\right) + \gamma_3\left(\text{Continuing}_{it} \cdot \text{Domestic}_j\right) \\ & + \gamma_4 \text{Policy}_t + \gamma_5 \text{Domestic}_j + \gamma_6 \text{Continuing}_{it} + \lambda_j + \varepsilon_{ijt}. \end{aligned} \tag{8}$$

The Policy_t^{2008} variable is 1 if the year is 2008, and 0 if 2007 or 2006 (two years are needed for an adequate sample). Here, β 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).

5.1 Parallel Trends

My empirical test compare domestic and foreign firms' response to the fuel economy policy. If their model characteristics were on similar growth paths, the effects that I observe are more readily interpretable as reactions to the policy. Although the Chinese auto industry

[35] β is $\left(\bar{Y}_{i=\text{Domestic},1} - \bar{Y}_{i=\text{Domestic},0}\right) - \left(\bar{Y}_{i=\text{Foreign},1} - \bar{Y}_{i=\text{Foreign},0}\right)$,

grew and changed dramatically between 2006 and 2012, the specification is valid if market shocks affected both foreign and domestic firms.

In Table 4, I present results from regressions that test for statistically different trends over time in model characteristics prior to the policy. The regressions, in which i indexes models, j firms, and t years, are of the form:

$$Y_{it} = \alpha + \beta \left(\text{Year}_t \cdot \text{Domestic}_j\right) + \gamma_1 \text{Year}_t + \gamma_2 \text{Domestic}_j + \varepsilon_{ijt}. \tag{9}$$

Year_t is a continuous variable ranging, in Panel A, from 2003 to 2008. 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 6. For example, the treatment effect on torque in my primary specification is 17 nm, compared to an estimated difference in prior growth path of -1.3 to 1.6 nm.

6 Results: Response to the Fuel Economy Standards by Firm Type

6.1 Policy Effect on Domestic Relative to Foreign Firms

I find 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 7) 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. The partial effect of being a domestic firm on torque is -32 nm of torque before the policy and -52 nm after (this result requires omitting firm fixed effects, shown in Table 10 column III). 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 similar albeit slightly smaller results. 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. Table 5 Panel C shows that with no sales volume requirement the effect is -$1,616 (significant only at the 10% level), but at a required sales volume of 5,000 vehicles, the effect is -$3,453, significant at the 1% level. Appendix A Table 3 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 6 shows results of the triple-difference estimation using the 2008 implementation of the policy for new models from Equation 8.[36] The coefficient of interest 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.[37] Note that the coefficients on the individual indicators and

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

[37]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.

interactions are not direct effects.[38]

An alternative explanation for the effects I observe is that simultaneously but unrelated to the policy, Chinese firms reduced price and vehicle quality to gain market share at the low end of the market. However, they did not gain market share in any segment after the policy. In Appendix A Figure 9, 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%.

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 2). 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. Appendix A Table 4 shows that with controls for vehicle class, the negative effect on weight is larger, but just barely insignificant. The weight distribution of new sales has become less peaked; a higher proportion of vehicles are either very light or very heavy, which reduces safety (Appendix A Figure 10). This interpretation is consistent with the literature on the counterproductive effects of attribute-based regulations, such as Aldy and Houde (2015) on the U.S. Energy Star program for household appliances.

6.2 Response to the Fuel Economy Standards by Ownership and JV Status

I evaluate the association between firm type and incentives to acquire technology by estimating Equation 7 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 7), and then combine them into

[38] 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.

a single specification (Table 8).

The dependent variables in Table 7 are torque in the left panels, and price in the right panels. These regressions compare subsets of domestic firms to foreign firms after relative to before the policy. Columns I.a-I.c restrict the sample to domestic firms with JVs and foreign firms: I.a includes all such firms, I.b SOEs with JVs, and I.c privately owned firms with JVs. The coefficients on the interaction term are all negative, significant, and of larger magnitude than the primary specification with all firms. Specification III considers SOEs, and V considers private firms. Column (a) indicates that the strongest negative impact of the policy on torque 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. Private firms with JVs reduced model maximum torque more than SOEs with JVs in response to the policy (III.c compared to V.c).

The right-hand panels of Table 7 conduct the same exercise with price as the dependent variable. In column (a), the strongest result is again for the subset of firms with JVs. This 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. There is no appreciable difference between SOE and private firm price reduction.

I jointly estimate the subsample effects in Table 8.[39] Column I confirms a stronger negative response among firms with JVs than firms without a JVs. 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 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.

[39]See Appendix A Table 5 for other characteristics.

Wald tests for these 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 reduction in model quality and price following the standards. The equilibrium quality choice for firms without JVs after the policy is higher than for firms with JVs, or in the notation from Section 3, $\phi_{i,JV} < \phi_{i,No\ JV}$. 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 of the JV $\left(\frac{\partial C_{i,JV}}{\partial \phi_i} < \frac{\partial C_{i,,No\ JV}}{\partial \phi_i}\right)$.

6.3 Robustness

This section focuses on key robustness tests using torque as the dependent variable. Analogous tests for other characteristics are in Appendix A. First, using all the data instead of a bandwidth around the policy yields essentially the same result as the primary specification (Table 9 column I).[40] I use a bandwidth of only one year, including data only from 2009 and 2008, in Appendix A Table 7. New models already faced the standard in 2008, so I expect the policy effect to be diluted. Indeed, the effects on torque and power are maintained, but the other characteristics lose their significance. Columns II and III of Table 9 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

[40]See Appendix A Table 6 for additional characteristics.

5,000 vehicles, the coefficient is -19 nm.[41]

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). Columns IV and V of Table 9 show that the effect on torque remains significant at the 1% level with no clusters and with firm-year clusters. I demonstrate the downward bias of standard errors in the conventional DD approach using all years, year fixed effects, and standard error clusters at the firm-year level in Panel B of Appendix A Table 6. The coefficients are misleadingly precise for for power and weight, which are only moderately significant in my primary specification. Appendix A Table 8 shows four alternative assumptions on the errors for all four characteristics: homoscedasticity, robust (sandwich estimator), year clusters, and firm-year clusters. The coefficient of interest is highly significant in all four alternatives for all four characteristics. The bias problem remains most severe with firm-year clusters.

I conduct placebo tests by estimating the DD design setting policy implementation at an alternative year. Columns VI-IX of Table 9 show results using 2006, 2007, 2008, and 2010. I find significant effects only when the placebo bandwidth includes 2009, and then the effects are barely significant and half the size of result using the actual policy.[42] 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 10. Omitting individual effects ($\text{Policy}_t, \text{Domestic}_j$) increases the coefficient on the interaction term to -40 nm (column I). 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.[43] 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).[44]

[41]See Appendix A Table 3 for additional characteristics.

[42]Appendix A Table 9 shows similar results for all characteristics.

[43]Appendix A Table 10 shows these specifications for all characteristics. The positive effect of being domestic on vehicle height is because a larger share of domestic firm production is SUVs.

[44]Appendix A Table 11 shows that for all four characteristics, there is a significant negative effect of the

I include vehicle class fixed effects in column VI of Table 10. There are four vehicle classes: compact, sedan, minivan, and SUV.[45] The omitted class dummy is compact; and unsurprisingly the other three classes have large relative positive effects. The coefficient on the policy interaction term declines somewhat to -15 nm (significant at the 5% level). Table 10 column VII uses OEM fixed effects, and also clusters standard errors at the OEM level. The number of groups is smaller; there are 69 groups (and so clusters) in OEM compared to 78 groups in firm. The coefficients and their significance are essentially unchanged.[46]

For the triple-difference estimation, Appendix A Table 12 shows that using alternative required sales volumes yields similar coefficients as the primary specification with equal or more precision. Appendix A Table 13 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 increases slightly in magnitude and becomes more precise. 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. Appendix A Tables 14 and 15 show placebo tests for the triple-difference design. The placebo tests generate negative coefficients for 2005, and mostly positive coefficients for the later years, but all are insignificant except for price in 2007, which has a coefficient of $899 (less than 1/4 the estimated policy effect).

I conduct a set of similar robustness tests for the firm type regressions in Appendix A Table 16. Specifications including only individual effects and the interactions are in columns I-IV. They confirm that domestic firms with JVs drive the policy's average effect. Columns V and VI exclude fixed effects, and columns VII and VIII use OEM fixed effects instead

policy regardless of whether I use year, firm and year, or no fixed effects.

[45] 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.

[46] See Appendix A Table 4 for class dummies and OEM f.e. for all characteristics.

of firm fixed effects. In both cases, the coefficients are slightly smaller than in the main specification. The negative effect of having a JV on firms' policy response also increases in model sales volume, shown in Appendix A Table 17. When models with at least 100 units sold are considered, the effect on torque is only -16, and on price -$2,079, both significant at the 5% level. At more than 5,000 units, the effects are -25 and $4,071, respectively, both significant at the 1% level. Finally, Appendix A Table 18 provides alternative standard error clustering. Similar downward bias of the errors is apparent, and all specifications remain significant at the 1% level.

7 Conclusion

When and at what rate firms learn helps explain income disparities across countries, and is pivotal to the effectiveness of infant industry protection. In Parente and Prescott's (1994) model, barriers to technology adoption - including regulatory constraints, corruption, or threat of violence - increase its cost and account for much of the cross-country income disparity. Evidence of such barriers increasing technology acquisition cost is scarce. The automotive industry is a good context to study this phenomenon, because absorbing new technology in the auto sector involves a particularly large amount of tacit knowledge in engineering, manufacturing, and other types of human capital (Ahrens 2013). Acquiring technology is costly, whether by own development, licensing, JVs, M&A, imitation, or theft. 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.

I show that Chinese automotive manufacturers responded to the 2009 implementation of fuel economy standards by reducing the torque, horsepower, weight, and price of their models. SOEs with JVs were primarily responsible for the negative effects of the policy on domestic firm quality and price. Further, 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. This is consistent with Thun's (2004) conclusions about JVs in China's auto sector. In a simple model, I explain how competing with the foreign partner may cannibalize the domestic firm's share of foreign brand profits.

Though Chinese firms may maximize profits, the absence of Chinese exports and the failure of Chinese firms to gain market share suggest that the down-market strategy has not thus far been successful. China's JV mandate, combined with substantial direct state ownership and high import tariffs, contrast with the Japanese, Taiwanese and Korean paths. They featured an absence of FDI and little direct cooperation with foreign firms, but intensive licensing of foreign technology and reverse engineering.[47] Poorly designed industrial policy may help explain why China's auto sector development has differed so dramatically from that of Japan and Korea. It is possible that in recent decades a more rigorous WTO regime and tighter IPR protection made it impossible to replicate the Japanese and Korean approaches. 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.

Conventional trade models, such as McGrattan and Prescott (2009, 2010), grossly overestimate China's FDI inflows and outflows due to an assumption that foreign firms bring their technological capital to China, which Chinese firms accumulate. When Holmes et al. (2013) add China's requirement that foreign firms transfer technology in order to invest, they are much better able to match their multi-country 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

[47] See Goto and Odagiri (2003), Kim (2003), and Aw (2003).

rather than innovate themselves. My results confirm this hypothesis: a distorted market structure leads foreign firms bring minimum technology to China, while JVs disincentivizes Chinese firms from investing in technology acquisition.

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)								
All								
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
Has JV								
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								
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								
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

D. Domestic Firm Ownership Matrix

		SOE	Privately owned	Total
	Firms with JV	37	3	**40**
Firm (brand) level	Firms without JV	6	22	**28**
	Total	**43**	**25**	
	Firms with JV	20	2	**22**
OEM level	Firms without JV	5	20	**25**
	Total	**25**	**22**	

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. Panel C 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.

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)
$\mathbf{1}\,\vert\text{Minivan}_i$	**-370**	**-2411**	**572**	**-2220**
	(761)	(2074)	(946)	(1465)
$\mathbf{1}\,\vert\text{SUV}_i$	**-2802*** **	**-7532*** **	**-3258* **	**-3265** **
	(950)	(2616)	(1818)	(1297)
$\mathbf{1}\,\vert\text{Sedan}_i$	**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. $1999 \leq \text{Year} \leq 2012$; *** indicates $p < .01$.

Table 4: Parallel Trends among Foreign and Domestic Firms prior to the Policy

A. All Characteristics, $2003 \leq \textbf{Year}_t \leq 2008$

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: Fuel Economy Policy Impact on Domestic Model Characteristics (DD)

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)
$Policy_t \cdot Domestic_j$	**-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)
$Policy_t \cdot Domestic_j$	**-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

C. Increasing Sales Volume (Dep. Var. is Price, 3 year bandwidth)				
Min. Model Sales Volume:	I. 0	II. 500	III. 1,000	IV. 5,000
$Policy_t \cdot Domestic_j$	**-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 domestic firm model characteristics relative to foreign firms (Equation 7). 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: Fuel Economy Policy Impact on Domestic Model Characteristics (triple-difference)

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 domestic firm model characteristics relative to foreign firms (Equation 8). 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 7: Fuel Economy Policy Impact on Domestic Model Characteristics (DD) in 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
$\text{Policy}_t \cdot \text{Domestic}_j^{JV}$	**-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
$\text{Policy}_t \cdot \text{Domestic}_j^{SOE}$	**-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
$\text{Policy}_t \cdot \text{Domestic}_j^{Priv.}$	**-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)
$\text{Domestic}_j^{Priv.}$	-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. Firm fixed effects omitted because the number of firms in certain categories is quite small. The unit of observation is the model-year. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 8: Fuel Economy Policy Impact on Domestic Model Characteristics (DD) in Jointly Estimated Subsamples

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 $p < .01$.

Table 9: Key Robustness Tests using Torque (Part 1)

Dependent Variable: Torque (nm)									
		Model sales volume		Standard error clustering		Placebo test with artificial policy at year			
	I. All yrs (1999-2012)	II. >100	III. >5000	IV. None (robust)	V. Firm-year	VI. 2006	VII. 2007	VIII. 2008	IX. 2010
$\text{Policy}_t \cdot \text{Domestic}_j$	**-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

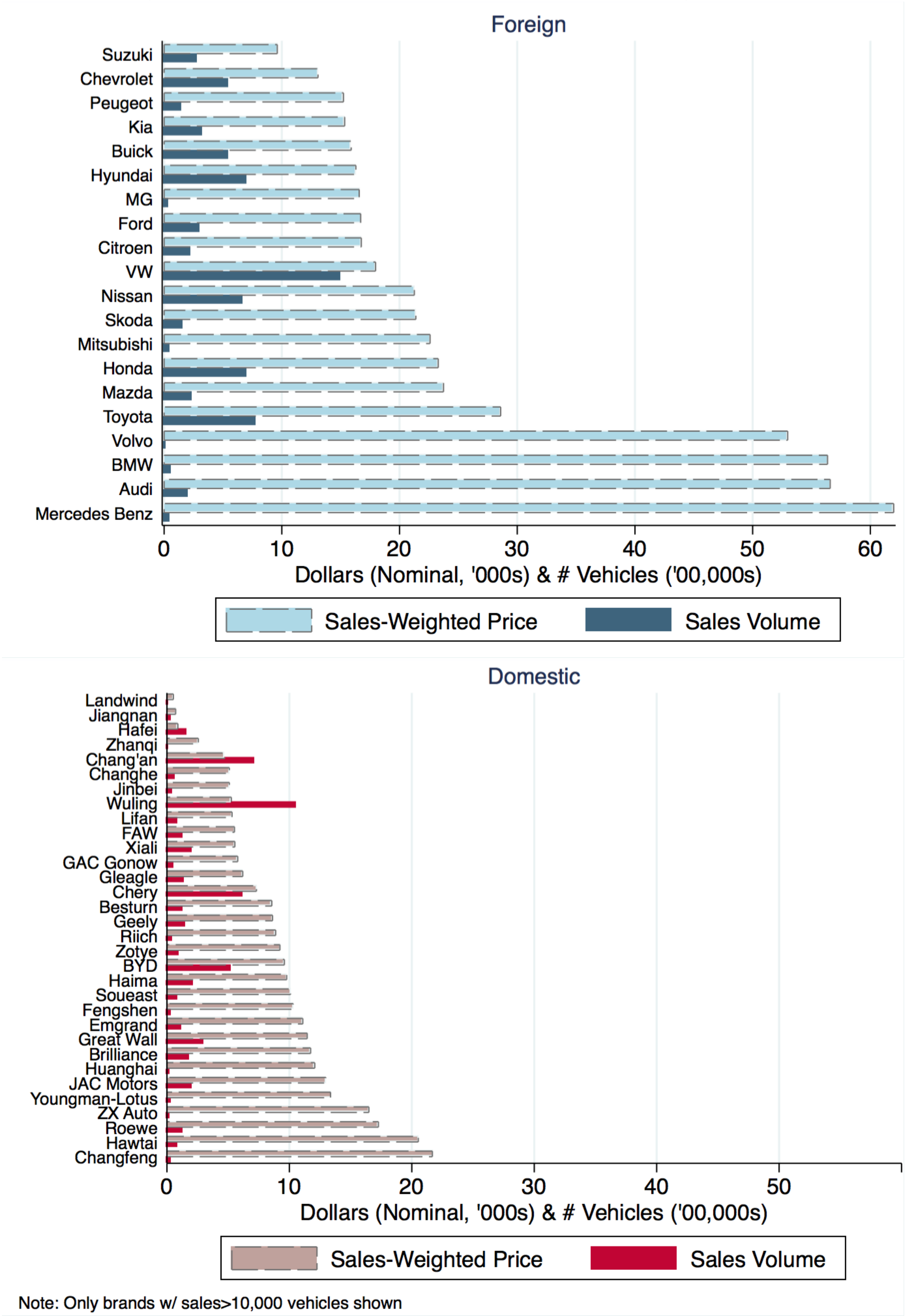
Note: This table reports regression estimates of the effect of the fuel economy standards on model torque (Equation 3). Sales volume is the number of units sold of that model-year vehicle. Except for columns II and III, only models with at least 1,000 units sold are included. Except for columns VI-VIII, 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 10: Key Robustness Tests using 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)
$\mathbf{1}\,\|\text{Minivan}_i$						51***	
						(12)	
$\mathbf{1}\,\|\text{SUV}_i$						82***	
						(14)	
$\mathbf{1}\,\|\text{Sedan}_i$						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

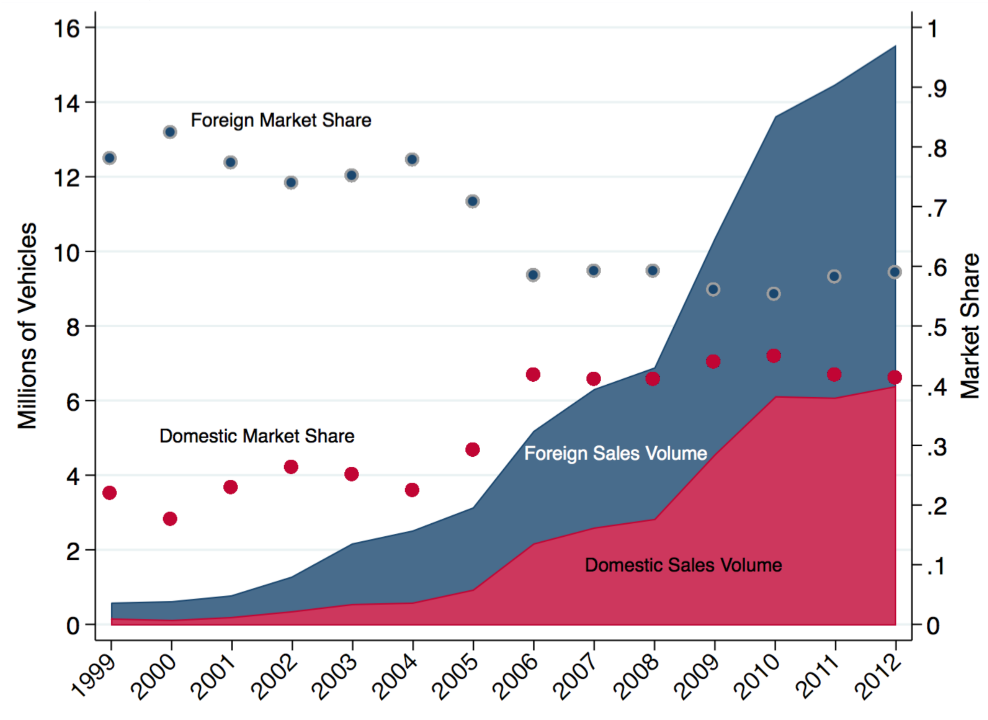
Note: This table reports regression estimates of the effect of the 2009 fuel economy standards on model torque, with a bandwidth of three years around 2009 policy (Equation 3). In column VI, there are fixed effects whether the vehicle class is Compact, Minivan, SUV and Sedan (Compact is omitted). In 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 $p < .01$.

Figure 1: Firm-Specific Sales Volume and Sales-Weighted Price, 2010



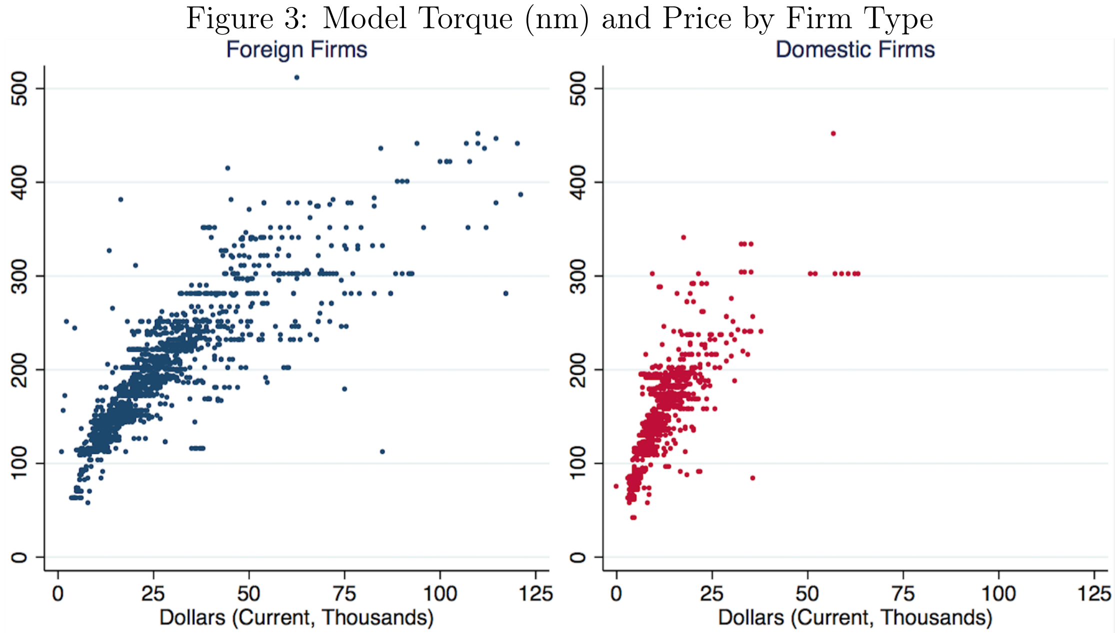
Note: This figure shows firm sales volume (number of vehicles) and sales-weighted average price across models sold for foreign firms (top graph) and domestic firms (bottom graph). Only data from 2010 is included.

Figure 2: Sales Volume and Market Share by Firm Type



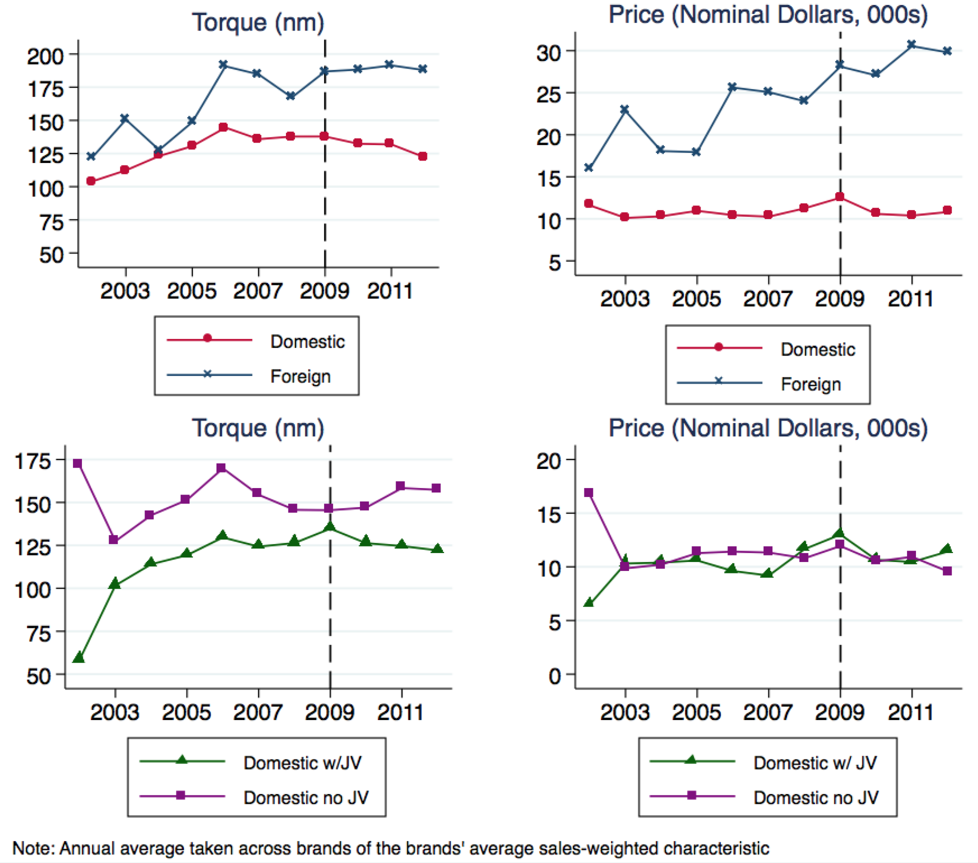
Note: This figure shows foreign and domestic brand Chinese sales volume (number of new vehicles sold in a given year) on the left axis, where the blue area is foreign and the red area is domestic. Market share of sales volume is on the right axis and in the foreign (blue) and domestic (red) scatterplot.

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



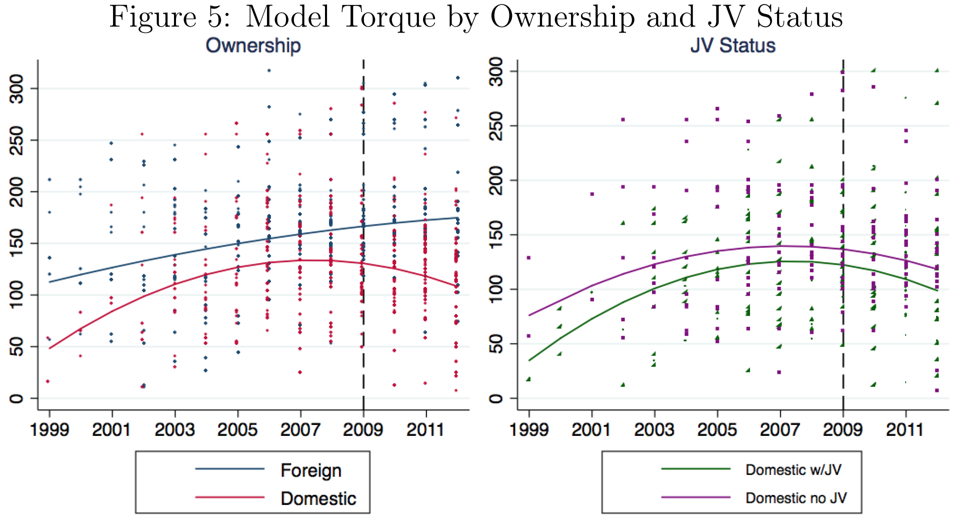
Note: This figure shows model torque (y-axis) and price (x-axis) for foreign firms and domestic firms. Each observation is a model-year, and all models sold between 1999 and 2012 are included.

Figure 4: Sales-Weighted Torque and Price by Ownership and JV Status



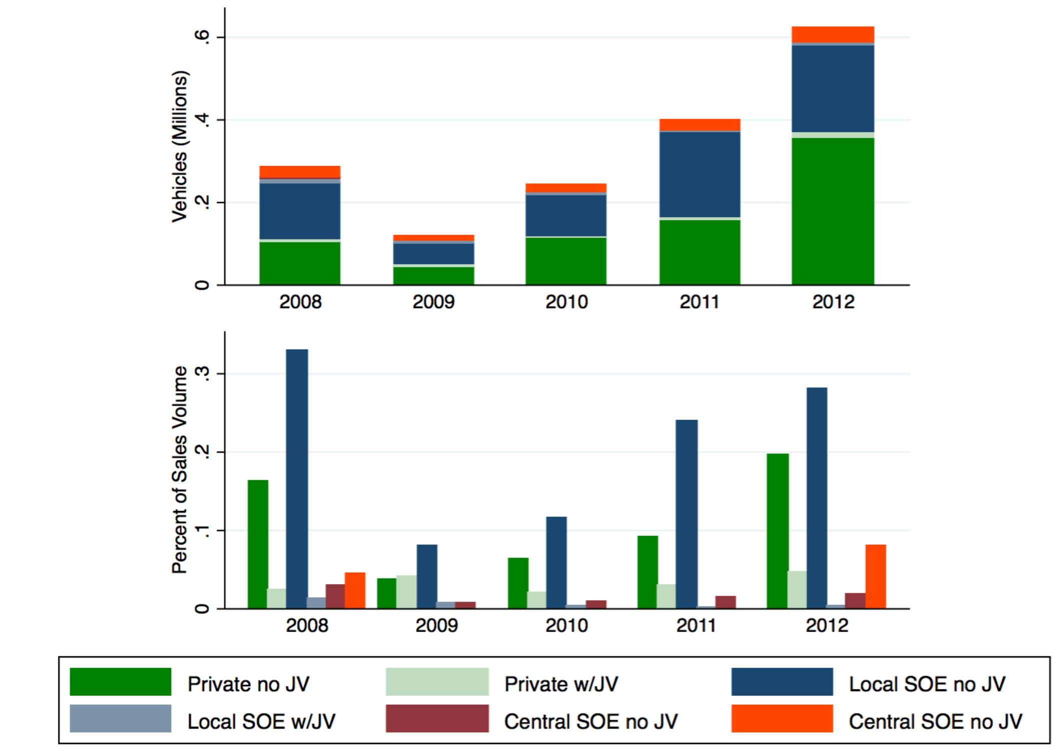
Note: This figure shows sales-weighted torque and price. The top graphs show foreign (blue) and domestic (red), while the bottom graphs divide domestic models by whether the firm has a JV (green) or not (purple). Average taken across firms of each firm's average sales weighted characteristic.

Figure 5: Model Torque by Ownership and JV Status



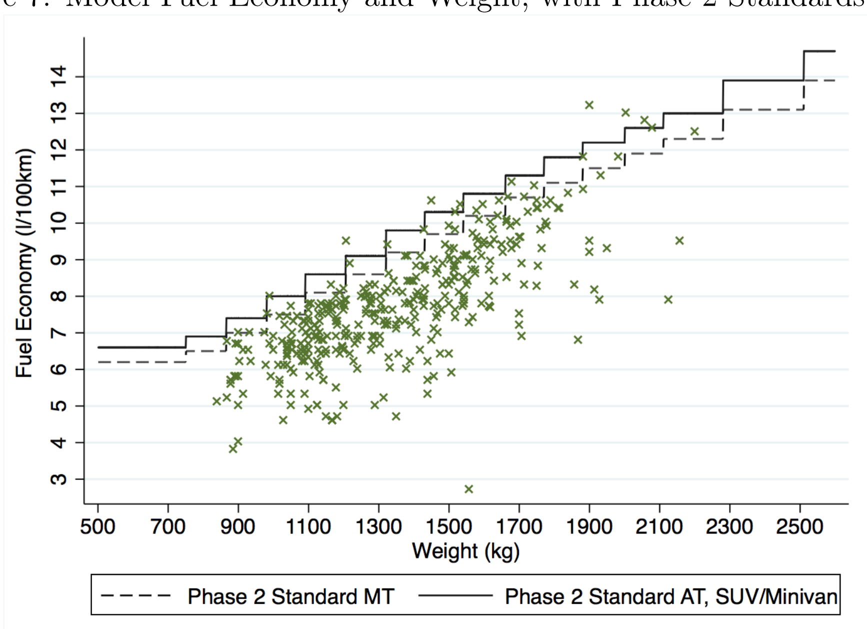
Note: This figure shows a scatter of model torque with fitted 4th degree polynomials. The left graph shows foreign (blue) and domestic (red), while the right graph divides domestic models by whether the firm has a JV (green) or not (purple).

Figure 6: Domestic Firm Export Volume and Percent of Total Sales Volume 2008-2012



Note: This figure shows Chinese domestic firm vehicle exports. Top: exports by ownership type. Bottom: exported fraction of total sales volume. For example, the first green bar in the bottom graph is exports divided by all vehicles sold among all firms that are privately owned and have no JV.

Figure 7: Model Fuel Economy and Weight, with Phase 2 Standards, 2010



Note: This figure shows China's 2009 Phase 2 fuel economy standards. Dotted line is for manual transmission, line is for automatic and all SUVs/minivans.

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