Joint Ventures and Technology Adoption

A Chinese Industrial Policy that Backfired

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Abstract

To spur technology transfer, developing countries have often required foreign entrants to form joint ventures (JVs) with domestic firms. I show that cannibalization incentives in a JV discourage domestic firm innovation, countering the benefits of greater knowledge spillovers. I examine China's auto sector as a case study. Recent fuel economy standards provide plausibly exogenous variation in the fixed cost of quality upgrading for domestic (Chinese) firms. I show that rather than invest in fuel efficiency technology, domestic firms met the standards by decreasing quality relative to foreign firms. The proxies for quality - power, weight, and price - decreased the most among firms with JVs. Surprisingly, the negative JV effect is stronger than the negative state ownership effect.

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"It's like opium. Once you've had it you will get addicted forever...From central authorities to local governments, everyone has been trying hard to bring in foreign investment. But so many years have passed and we don't even have one brand that can be competitive in the auto world."
– He Guangyan, Former Minister of Machinery & Industry, on joint ventures in China's auto sector[1]

1 Introduction

This paper explores how an industrial policy designed to induce technology transfer can backfire, perversely disincentivizing technology acquisition. Developing countries have often required foreign entrants to form joint ventures (JVs) with 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. However, JVs have two other important features. First, technology transfer requires the domestic partner to invest in innovation, regardless of whether the transfer occurs via tacit learning, licensing, stealing, or imitation. Second, the domestic partner receives a share of foreign brand profits.

In a stylized model, I show how this structure disincentivizes the domestic partner from investing in innovation that would yield substitutes to the foreign partner's models. Doing so would cannibalize the foreign profit stream. This is a version of the Arrow (1962) replacement effect, which causes monopolists to invest less in innovation. Pushing in the opposite direction is an adaptation of the Gilbert and Newbery (1982) efficiency effect, based on the assumption that the cost of technology acquisition is lower for domestic firms with JVs than without them. Whether firms with or without JVs innovate more is an empirical question; it depends on whether the negative effect of foreign partner profits outweighs the positive effect of lower technology acquisition cost.

As a case study, I focus on China's automotive industrial policy, which has called for globally competitive, high quality Chinese firms since the late 1970s.[2] A pillar of this policy has been allowing foreign firms to produce cars in China only through JVs with domestic

[1]Reuters. 2012. "China ex-minister says foreign auto JV policy 'like opium."' September 3.
[2]See, for example, State Council (1994, 2006).

firms. During the period studied here - 1999 to 2013 - the following example is illustrative of the JV structure: BMW manufactures in China through its JV with Brilliance Auto, a privately owned Chinese firm. Their JV plant produces only BMW vehicles. Brilliance helped finance the JV plant and receives fifty percent of profits from sales of China-manufactured BMWs. Brilliance produces its own brands at other plants, where BMW is not involved. I show that new fuel economy standards, which demand that heavier and more powerful vehicles have more advanced technology, led domestic firms with JVs (like Brilliance) to reduce quality and price. Foreign firms (like BMW) continued on an upward trajectory.

Foreign brands like Volkswagen, GM, and Toyota have consistently dominated the local market, particularly in the more profitable, higher priced segments. Nearly all foreign brand vehicles are produced in China through JVs, as high tariffs have precluded large-scale imports. The failure of China's auto industrial policy to produce brands that can compete even domestically is a puzzle that goes beyond the inefficiencies associated with state ownership. Although evaluating the effect of having a JV on innovation is challenging, it is relevant beyond China's auto sector. Brazil, Mexico, India, Nigeria, and Malaysia have mandated JVs, and China pressures foreign entrants to form JVs in other sectors.[3]

China's sudden and stringent 2009 fuel economy standards provide plausibly exogenous variation in the fixed cost of technology upgrading.[4] An automaker facing fuel economy standards can either add fuel efficiency technologies or reduce quality by decreasing power and/or weight. The fuel economy policy 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.

I show that after the policy domestic firms reduced quality and price relative to foreign firms, and did not gain market share. I use novel, reliable data, and comprehensive model-level sales and characteristics data for the Chinese auto market in a difference-in-differences (DD) design. I show that relative to foreign firms, the policy reduced domestic model price

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

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

and torque (a measure of acceleration and power) by 10%, and weight by about 5%. The variation is within-firm and robust to conditioning on sales volume. I demonstrate continuity in foreign firm vehicle characteristics, and assume that their technology transfer behavior did not change immediately around the policy.

I disaggregate the standards' impact along two dimensions: whether the firm has a JV, and whether it is a state-owned enterprise (SOE). In a split sample analysis, the negative effect is strongest for firms with JVs. It is present but smaller for SOEs without JVs, and disappears entirely for private firms regardless of their JV status. Few firms are SOEs without JVs or private with JVs, so the exercise suffers from a small sample problem. However, I am able to establish significance across effects using a quadruple interaction between the policy, JV, SOE, and domestic status, and including all triple, double, and single interactions. I confirm that JVs explain the negative effect of the policy. I also show that the negative policy effect is stronger among domestic firms who competed more intensively with their partner pre-policy; I use vehicle class share distribution as a proxy for competitive intensity.

My results support the hypothesis that a cannibalization threat disincentivizes innovation in technically lopsided JVs. The negative effect of increasing own quality on the share of JV profits appears to outweigh any advantage from knowledge spillovers. My findings 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]

As a robustness check, I use a second empirical approach that exploits the standards' staged implementation in a triple-differences design. New and continuing vehicle models faced the standards in 2008 and 2009, respectively.[6] I show that in 2008, domestic firms' continuing models were more powerful, more expensive, and heavier than new models already

[5] On (a), see Chen, Jiang, and Ljungqvist (2015), Hsieh and Klenow (2009), Fang and Lerner (2015), Allen et al. (2005), Khandelwal, Schott and Wei (2011), and Lin, Liu and Zhang (1998). On (b), see Ramachandran (1993), Moran (2002), Blomström, Kokko and Zejan (1992), and Urata and Kawai (2000). However, other studies find evidence of positive spillovers, like Javorcik (2004) and Dimelis and Louri (2002).

[6] 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.

subject to the policy, relative to the same comparison within foreign firms. The confirms the main result. Finally, I conduct a rich array of robustness tests, including placebo tests, alternative bandwidths around the policy, and varying fixed effects.

The JV mandate and the fuel economy policy were successful in two senses: foreign firms brought new technology to China, and fuel efficiency improved. However, *both* policies explicitly aimed to encourage domestic firm innovation. I find that both had precisely the opposite effect. I cannot assess whether the post-fuel economy policy decision to go down-market was profit maximizing. Regardless, it contrasts with the government's intentions.

My analysis is limited in scope. First, it addresses only short term responses to a technology cost shock. In the longer term domestic firms are likely to invest in innovation, and the presence of superior technology among foreign firms may be helpful. Second, the cannibalization channel that I propose may be at play among JVs more broadly, but it is not obvious that my empirical results generalize to JVs that are voluntary or where partners 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 regulates FDI.[7] More broadly, my results speak to a debate about post-World War II growth. On one hand, new growth theory advocates trade and investment openness to close technology gaps (Coe and Helpman 1995, Baldwin 1969). On the other hand, new institutional economists attribute the success of East Asian "Tigers" to government direction (Rodrik, Subramanian, and Trebbi 2004, Amsden 1989). I present causal evidence of an industrial policy failure. In my setting, the most innovative firms are the least touched by industrial policy.

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

China could have pursued alternatives to the JV mandate. One option was 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, such as Xiaomi and Lenovo. A second path, albeit more difficult under modern trade law, is Japan and Korea's infant industry protection combined with foreign technology licensing and reverse engineering. Despite a rich theoretical literature, there is little strong empirical evidence of the effectiveness of industrial policies that target technology upgrading.[8] An exception is Rotemberg (2015), who assesses the causal impact of industrial policy changes on firm productivity.

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 technical quality, rather than production functions and accounting-based productivity measures. Firm-level panel data is also relatively rare in 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, Srholec and Verspagen 2010, Figueiredo 2006).

The paper proceeds as follows. I provide historical context about the Chinese auto sector in Section 2. Section 3 presents a simple model of innovation incentives in a JV. I describe the natural experiment in Section 4, the data in Section 5, and the empirical strategy in Section 6. The results are in Section 7, and robustness tests in Section 8.

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

[8] Key theoretical work includes Bardhan (1971), Romer (1993), and Melitz (2005). For a review, see Harrison and Rodríguez-Clare (2010). Related to this paper is Müller and Schnitzer's (2006) theoretical model of technology transfer in international JVs. They focus on the role of government support in increasing the incentive of the foreign firm to share technology.

designated the automotive sector a "Pillar Industry," and it has subsequently described automobile production as key to China's development.[9] 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 produce low quality, low price models.

Beijing permits FDI in vehicle production only via partnerships with domestic firms. The domestic partners were supposed to evolve into multinationals competing in foreign markets (State Council 2006). High import tariffs historically made a JV the only way a foreign firm could access China's market.[10] In the period studied here, the JV is a stand-alone enterprise producing only foreign brand cars. 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. 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. State owned enterprises (SOEs) are majority owned by provincial governments (local SOEs) or the central government (central SOEs). 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. The literature on China's economy has focused on the efficiency of SOEs relative to private

[9] 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)

[10] Tariffs have been 180-220% through 1994, 70-150% through 2001, 30% through 2005, and 25% thereafter. Appendix 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. Deng and Ma (2010) estimate that between 1995 and 2001, Volkswagen had a 41% market share and markups of 42%.

firms.[11] However, in some high-tech sectors, firms with at least 50% state-ownership have become globally competitive, dominating the domestic market and achieving meaningful exports.[12] 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.

In negotiations to establish the early auto JVs, foreign firms benefited from information asymmetry about auto manufacturing. JVs initially used outdated technology to bound potential technology transfer (Oliver et al 2009). 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).[13] 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 marketed itself as a purveyor of useful technology, but the joint research center it established with its Chinese partner 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, further distancing GM's China operation from Detroit's state-of-the-art (Tang 2012). Foreign firm behavior is not the focus of this paper, but it appears to be consistent with Branstetter and Saggi (2011), who theorize that stronger intellectual property rights reduce imitation risk, increasing FDI and innovation incentives.

Policies like the 1994 directive were unenforceable. Instead, market discipline compelled foreign firms to produce the latest models in China by the mid-2000s. Competition came from a number of fronts. First, as in other sectors auto 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

[11] See Khandelwal et al. (2011), Bajona and Chu (2010), Jefferson et al. (2003), and Lin et al. (1998).

[12] Examples are wind turbine company Goldwind, shipbuilding company China State Shipbuilding Corporation, and steel manufacturer Baosteel.

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

firms with and without JVs increased from 2 to 11, and 1 to 17, respectively (see Appendix Figure 2). 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 has consistently called for "self-reliant Chinese car manufacturers who rank among the 500 largest global firms" (NDRC 2004). Yet the popular press generally provides a narrative of failure: "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); and "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). Liao Xionghui, the Vice President of Lifan, a private Chinese automaker was quoted in 2012 as saying "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." (Ying 2012).

3 Joint Ventures and Incentives to Innovate

There is ample anecdotal evidence that (a) JVs failed to achieve technology transfer; and (b) domestic firms have not developed innovation and design capability.[14] The JV industry structure may attenuate innovation incentives. Producing substitutes to foreign partner models cannibalizes the domestic firm's share of JV profits.

Consider the following stylized profit functions for domestic firms:

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

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

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

where j denotes firm, i denotes model, ϕ technology quality, and s the domestic firm's profit share from foreign model sales. I assume a competitive market, and that $\frac{\partial p_i}{\partial \phi_i} > 0$, $\frac{\partial q_i(\mathbf{p},\phi_i)}{\partial \phi_i} > 0$ and $\frac{\partial q_i(\mathbf{p},\phi_i)}{\partial p_i} < 0$. The firm's cost function ($C_i = \mathcal{F}(\cdot, \phi_{\mathrm{i}})$) is also increasing in quality $\left(\frac{\partial \mathcal{F}}{\partial \phi} > 0\right)$.

Suppose the cost of acquiring fuel efficiency technology is $F_j(\phi_i)$, which is fixed and additive (though it need not be). Then $C_i = \mathcal{F}(\cdot, \phi_{\mathrm{i}} + \mathrm{F_j}(\phi_{\mathrm{i}}))$.[15] The foreign firm already possesses the technology, so $F_{foreign} = 0$. Firms with JVs have greater access to foreign firm technology than firms without JVs, so $F_{j,JV} \leq F_{j,No\ JV}$. Holding other aspects of the cost function fixed, I therefore assume that increasing quality is no cheaper for firms with JVs than for firms without JVs, or $\frac{\partial C_{i,JV}}{\partial \phi_i} \leq \frac{\partial C_{i,No\ JV}}{\partial \phi_i}$.

The first order conditions in quality are:

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

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

The foreign firm's profit decreases in a competitor's quality $\left(\frac{\partial \pi_{JV}^{foreign}}{\partial \phi_i} < 0\right)$. Thus the domestic firm's investment in own quality reduces its marginal profit from the JV.[16] This is a version of the Arrow replacement effect: when a competitive firm and a monopolist have

[15] In fact, the fixed cost of technology acquisition is to some degree spread across models. I abstract from this here, though it applies if we assume equal spreading and equal number of models across firms.

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

the same profits from an innovation, the monopolist has a lower incentive to invest in R&D because he earns profits on the existing technology that would be cannibalized by sales of the new technology (Arrow 1962). Here the "monopolist" is the domestic firm with a JV, and the "competitive entrant" is the domestic firm without a JV. The Arrow replacement effect comes from the fact that $\frac{\partial}{\partial \pi_{JV}^{foreign}} \left(\frac{\partial \pi_j}{\partial F_j} \right) < 0$ (see Fudenberg and Tirole 2013). The more profit the domestic firm gets from its JV, the lower the incentive to spend F_j to acquire the new technology.[17]

Countering the replacement effect is what Gilbert and Newbery (1982) call the "efficiency effect." The monopolist is assumed to be more efficient in making profits than a duopoly, so its preemptive payoff is larger than the entrant's. The parallel assumption in the JV context is that domestic firms with JVs have a lower cost of technology acquisition ($F_{j \in JV} \leq F_{j \in No\ JV}$). Investment in fuel efficiency technologies are incremental and relatively certain. In the Gilbert and Newbery version of the model, this setup will make the preemptive payoff higher and the efficiency effect dominant.

Thus the theory is ambiguous about whether firms with or without JVs have a greater incentive to invest (pay F_j) and achieve higher quality (ϕ). It depends on whether the negative effect on ϕ of access to the foreign firm's profits (Arrow replacement effect) outweighs the positive effect of a lower technology acquisition cost (Gilbert Newbery efficiency effect):

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

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

The model also implies that among domestic firms with JVs, those that compete more intensively with their partners should be less incentivized to upgrade (they have a more negative $\frac{\partial \pi_{foreign,\ JV}}{\partial \phi_i}$). I proxy for competition using vehicle class shares, and test whether the results are stronger when I limit the comparison to partner firms that were both

[17]Note that the cannibalization effect also exists across models within each firm. When a firm expands its automotive technology frontier it generally takes market share from incumbents in a higher-value segment, and my focus here is on the JV effect on the within-firm choice to expand that frontier.

producing a similar distribution of classes prior to the policy.

4 The Fuel Economy Standards

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). The standards were anticipated by automakers, who had time between 2004 and full implementation in 2008-09 to tweak existing assembly processes and plan new models to meet them.

There is a basic tradeoff between vehicle fuel economy and, primarily, weight and power. 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 acquire fuel efficiency technology in order to meet the standards and maintain quality. These include discrete engine parts like catalytic converters and whole-vehicle design improvements in the power-train, aerodynamics and rolling resistance.[18] Heavier and more powerful vehicles generally have higher profit margins than other segments (IMF 2006).

Knittel (2011) examines the trade-offs in the U.S. auto industry. He shows, for example, that decreasing weight in passenger cars by 10% is associated with a 4.2% increase in fuel economy.[19] To maintain existing models' quality, the fuel economy standards compelled domestic automakers to acquire fuel efficiency technologies and integrate them into the model

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

[19]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).

design ($F_j(\phi_i) > 0$). Conversely, foreign firms - which had faced stringent fuel economy standards in Japan and Europe for decades - merely had 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 $F_{foreign} = 0$. 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. A number of studies conclude that the initial 2006-07 standards were not binding.[20] Phase 2 came into effect in January 2008 for new models, and January 2009 for continued models. Phase 2 is more stringent than current U.S. standards, but less stringent than Japanese and European standards (Appendix Figure 3 compares standards across countries).[21] My interviews in 2013 at 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.[22] I use 2009 as the policy implementation year in my primary estimation.

The Chinese standards are designed to be stricter for heavier vehicle classes (An et al. 2011).[23] Before the standards, automakers selling vehicles in China did not have to report fuel economy. Further, government inspection and enforcement were lax prior to the Phase 2

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

[21] 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.

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

[23] 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 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).

implementation. It is thus difficult to compare fuel economy before and after the standards. Figure 1 shows reported 2010 new vehicle fuel economy alongside the Phase 2 standards. Assuming accurate reporting, the vast majority of models met the standards.[24] Appendix Table 1 lists the standards by weight class.

5 Data and Descriptive Statistics

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.[25] 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.[26]

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).[27] Descriptive statistics at the model-year level, sorted by firm type, are in Table 1.[28] Figure 2 provides an overall sense of the market's evolution. Sales increased from under 1 million units in 1999 to 16 million units in 2013; the foreign market

[24]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.

[25]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.

[26]OEM refers to the firms that design, assemble and brand vehicles such as Ford and Hyundai. There are three vehicle classes: sedan, minivan, and SUV. Engine displacement is in liters. Powertrain is either internal combustion engine, natural gas, electric, or hybrid electric.

[27]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.

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

share declined from about 80% in 1999 to 60% in 2006. Since the 2009 policy, domestic firm market share declined somewhat from about 45% to 39% (note that these figures exclude imports). Variety increased as well; the number of models increased fairly linearly from 23 in 1999 to 426 in 2012.

I focus the analysis on three indicators of quality: price, torque and weight. Price is a particularly good indicator of quality in the auto market, conditional on achieving significant sales volume. The marketing literature has established that consumers perceive higher priced cars as higher quality, and presume that higher quality cars are higher priced (Keyes, 2009, Brucks et al. 2000.) In the analysis I use nominal local currency (RMB) prices to avoid issues around inflation and exchange rates (inflation will be differenced out). In Table 1 I show contemporaneous nominal dollar prices as well. The average price in the data is 136,000 RMB, and when weighted by sales (within firm), declines to 122,000 RMB, or almost $17,000.

Vehicle torque, responsible for acceleration and power, is a useful indicator of high technical quality.[29] 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. Horsepower is torque multiplied by a given speed (rotations-per-minute, or RPM), and determines the top speed of the vehicle. A model's advertised torque is the maximum achieved at a particular RPM. More power at lower speed is better, so lower RPM is indicative of higher quality. In the analysis, I normalize torque by dividing maximum torque by the RPM at which this maximum is reached.[30]

In general, heavier cars have more amenities and are safer. The easiest way to meet fuel economy standards, however, is to reduce weight. Cheap light-weighting strategies result in flimsier, smaller cars with fewer amenities. However, observing a change in weight alone is insufficient, because it is possible that automakers are substituting more advanced lightweight materials for steel. Aluminum, carbon fiber, and plastics are increasingly part

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

[30]I then multiply by 100, because in native units RPM is about 2 orders of magnitude larger than torque.

of the fuel efficiency technology repertoire for advanced automakers, like BMW and Ford. Therefore, I can conclude that domestic firms are taking the smaller, flimsier approach to lightweighting only if I also observe declines in torque and price.

Panel 1 of Table 2 shows correlations among the variables. By construction, torque and horsepower are closely connected: after a normalization for RPM, their correlation is 0.96. Sales volume is negatively correlated with price and quality, as is expected. The correlation between weight and price is 0.67, and between torque and price is 0.51. I log torque and price because they exhibit significant positive skewness, while the distribution of weight is roughly normal and, importantly, symmetric. All three densities are shown in Appendix Figure 4.

I use brands as the unit of analysis in descriptive statistics and primary estimations. Examples of brands are Ford, Audi, BYD, and Roewe. Top brands are graphed in Figure 3 for 2003, 2008 and 2013. The graphs show how Chinese brands have proliferated, while their sales-weighted dollar prices have actually decreased. VW has remained the largest foreign producer by sales volume, but its hugely dominant position in 1999 has been considerably eroded. The graphs show that despite their lower prices, Chinese firms do not dominate at the low end of the market.

To avoid confusion, I henceforth 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. There are a total of 3,177 models with sales of at least 1,000 units, of which I have price for 3,128, torque data for 2,726, and weight for 2,643. (In the analysis I exclude firms with sales of less than 1,000 units as these are not typically legitimate models, but are rather aimed to be showroom models or token alternative fuel efforts.)

JVs are not exogenously assigned, making it difficult to disentangle the effects of state ownership and JV status. Panel 2 of Table 2 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. Appendix Table 2 replicates Table 1 among domestic firms, dividing them by JV and SOE status. Among SOEs there are 797 model years, compared to 486 for private domestic firms. Among SOEs with JVs there are 456 model-years, compared to 82 for domestic private firms with JVs.

Empirically, exporting is strongly associated with firm productivity and competitiveness.[31] Chinese central government policy also explicitly targets auto exports (State Council 2009). Total exports remained small in 2012, at 0.6 million units. 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 4.[32] Between 2008 and 2012, private firms without JVs exported 10-20% of their 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).

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

[32] 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, such as Chery.

6 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. 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. The fuel economy policy, which put domestic firms at a fixed cost disadvantage in technology upgrading, is the treatment. Foreign firms are the "control;" 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. 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. 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.[33] In my primary specification, I pool the data on either side of the cutoff and cluster standard errors in 78 groups.

My primary specification is as follows:

$$\begin{aligned} Y_{it} \;=\; & \alpha + \beta\left(\text{Policy}_t \cdot \text{Domestic}_j\right) + \gamma_1 \text{Policy}_t + \gamma_2 \text{Domestic}_j \\ & + \gamma_3 \text{Sales Volume}_i + (\mathbf{1} \mid \text{Firm/Model/Class} = j/i/k) + \varepsilon_{ijt}. \end{aligned} \tag{6}$$

The coefficient of interest β is the effect of the policy on domestic firms relative to foreign

[33] See Bertrand, Duflo and Mullainathan (2004).

firms.[34] Each observation is a model-year (such as the VW Jetta in 2010). Model level data is subscripted with i (such as the BYD F6 or the Chevrolet Spark), firms with j (such as Chery or Honda), and the year with t. The outcome Y_{it} is log torque, log price, or weight. Price and torque are logged because they are strongly positively skewed, whereas weight has a symmetric, approximately normal distribution.

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 (such as BYD or Chery), and 0 if it is foreign (such as Nissan or GM). In the primary specification I use a bandwidth of three years on either side of the policy, condition on sales volume and control for firm fixed effects. Also, I require models to have sales volume of at least 1,000 vehicles.Thus all variation is within firm, and a minor car with odd characteristics cannot bias the results.

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 8. In Section 8, I also exploit the staged policy for new and continuing models in a triple-difference specification.

I alter the main specification to test implications of the model in Section 3. First, I interact the policy effect with firm JV and SOE status. The regression includes the quadruple interaction to estimate the effect of the policy on domestic firms that are SOEs with JVs, and all triple interactions for the policy effect of firms that have JVs but are private, and firms that are SOEs but do not have JVs.

$$\begin{aligned} Y_{it} &= \alpha + \beta_1 \left(\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j\right) + \beta_2 \left(\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV}_j\right) \\ &\quad + \beta_3 \left(\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{SOE}_j\right) + \beta_4 \left(\text{Policy}_t \cdot \text{Domestic}_j\right) \\ &\quad + \beta_5 \left(\text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j\right) + \gamma_1 \text{Policy}_t + \gamma_2 \text{Domestic}_j + \text{Has JV}_j + \text{SOE}_j \\ &\quad + \gamma_3 \text{Sales Volume}_i + (\mathbf{1} \mid \text{Firm/Model/Class} = j/i/k) + \varepsilon_{ijt}. \qquad (7) \end{aligned}$$

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

The coefficients of interest are β_1 through β_4, where β_4 gives the effect for private firms without JVs. I include the domestic individual effect because while no SOEs are foreign, all foreign firms have JVs.

Second, I test the effect of pre-policy competition. I expect that any negative effect of the policy will be stronger among domestic firms who are competing more directly with their JV partner. I proxy for pre-policy competition using the fraction of SUVs and minivans that a firm produces. That is, the cannibalization effect should be smaller if the foreign partner produces mostly sedans while the domestic firm produces mostly minivans. I construct indicators as follows. I sum a firm's annual minivan/SUV sales and divide it by total sales, then take the pre-policy mean and identify a firm as a minivan/SUV producer if it is non-zero/more than 50% (most firms do not produce minivans at all). I then estimate Equation 6 on the subsample of partner firms competing in the same class. An example of such a pair for SUVs is BAIC ("Beiqi") Zhanqi and partner Hyundai. For minivans, an example is Jiangling Motors (JMC) Landwind and partner Ford.

7 Results

I find that domestic firms responded to the 2009 fuel economy standard by manufacturing less powerful, cheaper, and lighter vehicles. I first demonstrate the results graphically using a series of scatterplots, where each dot is the average across models in a given year. Figure 5 introduces the data by showing raw prices for all years, with foreign firms in the left panel and domestic firms in the right panel. Domestic firms dropped their prices dramatically in 2009, while foreign prices were unchanged (note the axes are not the same). Figures 6 and 7 show the data used in estimation with common axes: logged torque and price in the three year window around the policy. These figures provide visual evidence for continuity around the policy among foreign firms (see Section 8 for tests). Among domestic firms, both torque and price jump downwards in 2009, the year of the policy. Afterwards, domestic firms increased torque, but did not subsequently reach their pre-policy level.

Figures 8 and 9 show domestic firm torque and price by JV and SOE status. It is clear that the fall around the policy is due to firms with JVs - both SOEs and private firms. Private firms seem to have been on a decreasing trend pre-policy, which is consistent with the more successful Chinese firms like Geely and Great Wall aiming to capture lower-end market share.[35]

Estimates of Equation 6, using a three year window on either side of the policy, are in Table 3. I find that the standards reduced vehicle torque and price in domestic models relative to foreign models by 10% (both significant at the 5% level). The standards reduced weight by 60 kg, or about 5% of the mean. (Recall that I log torque and price due to their positive skewness, while the distribution of weight is symmetric.) Panel 1 columns I-III show the unconditional effect with firm fixed effects, while Panel 2 columns I-III show the effect conditional on sales volume, which controls for market share; if domestic firms reduced price to gain market share in certain segments, the effect of the policy should disappear with this control.[36]

In Panel 2 columns IV-VI, I show the main result for all years (1999-2013), conditional on sales volume. More data provides greater power, and I find find larger and more significant effects of the policy on all three characteristics. The negative effects of the policy on domestic firm price and weight increase, while the effect on torque remains roughly constant. This provides reassurance that domestic firms did not catch up to foreign firms in 2012 and 2013, despite the increasing trend from Figure 6. In Panel 1 column IV I limit the variation to within-model, and still find a significant negative effect on torque, albeit a smaller one than with firm fixed effects. In columns V and VI I use firm and class (SUV, minivan, sedan) fixed effects, and find roughly similar results. I do not find effects on length or height, which is to be expected as they are poor proxies of quality.

[35]Weight graphs are omitted for brevity.

[36]Note that the R^2 is very small in most specifications (typically under 10%). This is because the regression procedure I use (xtreg, fe) treats the groups (e.g. firms) as fixed objects and subtracts them from the model before estimating fit.

I directly test the implications of the model in Tables 4-6. I first estimate Equation 6 on subsamples of domestic firms in Table 4. When only domestic firms with JVs are included (column I) along with all foreign firms, the negative effect of the policy is much stronger, at -15% for torque, -17% for price, and -94 kg for weight. These are significant at the 5%, 5%, and 1%, respectively. When I limit the domestic sample to SOEs and SOEs without JVs (column II), the effects are lower, albeit still significant for all three characteristics and slightly higher than the whole sample effect. Coefficients decrease slightly for SOEs without JVs. The effects among private firms with and without JVs (columns IV and V) are insignificant for all characteristics, and the coefficients are much smaller in magnitude, and near zero for private firms without JVs.

I estimate Equation 7 in order to establish that these coefficients are significantly different from one another and that the strong JV effect is not the result of SOEs. In Table 5 the policy-domestic interaction is further modulated by JV and SOE status. The coefficients are relative to foreign firms, and the omitted dummy in the interaction with domestic firm types is private firms. I report the three-way interactions and the quadruple interaction. Panel 2 differs from Panel 1 only in its control for sales volume.

This estimation confirms that domestic firms with JVs are responsible for the negative effect. The effects are again roughly double for firms with JVs: -16% for torque, -20% for price, and -111 kg for weight (significant at the 10%, 1%, and 10% levels, respectively). The weight effect is about 9% of the mean among domestic firms. The quadruple interaction and remaining three-way interactions are insignificant, except for the effect of having a JV and being an SOE on weight, which is large and negative; these vehicles are 259 kg lighter than those of private firms without JVs. Controlling for sales volume in Panel 2 causes the weight effect to lose significance. The robust torque and price effects, however, suggest that 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, $\phi_{i,JV} < \phi_{i,No\ JV}$.

I turn to competition intensity in Table 6. Panel 1 includes only the subset of JV partners whose sales were majority SUVs in the three years before the policy. I do not use firm fixed effects because the sample is so small. Although I do not find a significant negative effect on price, I do find that the effects on torque and weight are much stronger than in the primary specification, at -23% and -172 kg, significant at the 5% and 1% levels, respectively. In Panel 2 I include partners that produced minivans before the policy, and here I find stronger and highly significant effects for all three characteristics. The effect is -16% for torque, -15% for price, and -99 kg for weight, significant at the 1%, 1%, and 5%, respectively. Minivan production may better proxy for competition, as they are a more niche product and produced by fewer firms overall. Overall, these findings are consistent with a story in which the negative effect of own ϕ_i on the foreign partner's profits $\left(\frac{\partial \pi_{foreign,\ JV}}{\partial \phi_i}\right)$ is stronger among firms that are more competitive with their partner.[37] Together, these effects outweigh any technology acquisition cost advantage of the JV. A central objective of industrial policy is usually either to increase or decrease competition. In the presence of the distorting JV profit cannibalization incentive, it seems that more competition from the foreign firms has a *negative* impacts on innovation incentives.

8 Robustness

This section first establishes parallel trends across foreign and domestic vehicles, then provides a more stringent alternative specification of the main result exploiting the staged policy implementation, and finally describes a variety of standard robustness tests.

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

[37] I also created a location-based competition index based on the number of foreign JV plants in a given province or city. However, interacting the main effects with this index did not yield systematically different effects across groups.

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

In Appendix Table 3, 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

$$Y_{it} = \alpha + \beta \left(\text{Year}_t \cdot \text{Domestic}_j\right) + \gamma_1 \text{Year}_t + \gamma_2 \text{Domestic}_j + \varepsilon_{ijt}. \tag{8}$$

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. The $\hat{\beta}$ coefficients are all tiny in magnitude and insignificant. The time trend (continuous year variable) is mostly positive and slightly significant, reflecting the fact that quality generally improved over time prior to the policy.

Triple-Differences

I exploit the staged policy implementation in a triple-differences design. 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:

$$\begin{aligned} Y_{it} \;=\; & \alpha + \beta \left(\text{Policy}_t^{2008} \cdot \text{Domestic}_j \cdot \text{Continuing}_{it}\right) + \gamma_1 \left(\text{Policy}_t^{2008} \cdot \text{Domestic}_j\right) \\ & + \gamma_2 \left(\text{Policy}_t^{2008} \cdot \text{Continuing}_{it}\right) + \gamma_3 \left(\text{Continuing}_{it} \cdot \text{Domestic}_j\right) \\ & + \gamma_4 \text{Policy}_t + \gamma_5 \text{Domestic}_j + \gamma_6 \text{Continuing}_{it} + \lambda_j + \varepsilon_{ijt}. \end{aligned} \tag{9}$$

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).

Table 7 shows results of the triple-difference estimation using the 2008 implementation of the policy for new models from Equation 9.[38] The coefficient of interest is positive and significant for all four characteristics, showing that continuing domestic models not subject to the policy were more powerful, more expensive, and heavier than their new models, relative to the continuing-new difference among foreign firms.[39] Note that the coefficients on the individual indicators and interactions are not direct effects.[40]

Additional robustness tests

This section focuses on key robustness tests of the main, full sample result using torque as the dependent variable. Analogous tests for other characteristics and firm-type results are in the appendix. In Table 8 Panel 1 I first show the Policy_t and Domestic_j interaction and individual effects in Columns I and II. The coefficient on the interaction is -7%, significant at the 10% level, without the individual effects. Columns III and IV show that the result is robust to using no fixed effects and both year and firm fixed effects. Column V replaces the sales volume requirement of 1,000 units with 5,000 units, and shows that the result is unchanged at -11%.

Panel 2 of Table 8 shows that the result is robust to alternative assumptions about standard errors: brand-year, robust (no clusters), and two-way clustering (the Cameron-Gelbach-Miller approach, implemented using Stata's extended instrumental variables (ivreg2) command. Columns IV and V of Panel 2 conduct placebo tests in which the policy is artificially set to 2006 and 2005. The coefficients are insignificant, at 2.5% for 2006 and 5.9% in 2007. There 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

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

[39]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.

[40]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.

its pre-crisis growth path by 2010 (Diao et al. 2012).

9 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 and corruption - help explain cross-country income disparity. I present evidence that the JV mandate in China's auto sector is a distortionary barrier to technology adoption, a finding that is consistent with the political science literature on JVs in China (Thun 2004).

China's JV mandate, substantial state ownership, and high import tariffs contrast with the development of the auto sector in Japan, Taiwan, and South Korea. They featured an absence of FDI and little direct cooperation with foreign firms, but intensive licensing of foreign technology and reverse engineering.[41] Poorly designed industrial policy may help explain why China's auto sector development has differed so dramatically. A more rigorous WTO regime and tighter IPR protection may also have made it impossible in recent decades to replicate the earlier approaches.

Though Chinese firms may maximize profits, the absence of Chinese exports and the failure of Chinese firms to gain market share suggest that their down-market strategy has not thus far 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 enable Chinese firms 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. They assume that foreign firms bring their technological capital to China, which Chinese firms accumulate. When Holmes, McGrattan

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

and Prescott (2013) add China's requirement that foreign firms transfer technology in order to invest, they are much better able to match their model to moments in the data. They conclude that FDI decreases when foreign firms must transfer technologies and that Chinese firms prefer to appropriate the foreign capital rather than innovate themselves. My results confirm this hypothesis: JVs cause foreign firms bring minimum technology to China and disincentivize Chinese firms from investing in technology acquisition.

Table 1: Model-Level Summary Statistics by Firm Type

	Price (RMB)*	Sales Volume	Sales-Wtd Price (RMB)	Sales-Wtd Price ($)	Torque†	Normalized Torque††	Weight (kg)	Height (mm)	Length (mm)
Panel 1: All Firms									
Mean	136,089	31,209	122,340	16,834	170	4.33	1,332	1,546	4,422
Median	103,900	13,882	109,169	14,870	156	3.80	1,304	1,483	4,500
Std Dev	103,755	55,186	81,684	11,694	59.7	2.19	298	156	416
N	3,128	3,177	3,194	3,087	2,726	2,715	2,643	2,723	2,724
Panel 2: Foreign (Non-Chinese) Firms Pre-Policy									
Mean	168,673	24,574	151,268	20,191	179	4.62	1,349	1,512	4,456
Median	131,800	11,867	133,618	17,655	170	4.00	1,304	1,472	4,520
Std Dev	112,308	33,417	85,141	11,400	57.6	2.26	283	107	395
N	437	438	438	436	405	405	405	410	410
Panel 3: Foreign (Non-Chinese) Firms Post-Policy									
Mean	171,892	33,560	153,595	22,669	190	4.81	1,382	1,520	4,492
Median	134,800	17,302	137,528	18,510	177.5	4.08	1,386	1,484	4,540
Std Dev	114,900	43,482	78,291	12,097	62.4	2.69	282	101	363
N	639	644	644	642	610	610	598	610	610
Panel 4: Domestic (Chinese) Firms Pre-Policy									
Mean	83,763	25,845	82,704	9,860	146	4.04	1,285	1,606	4,338
Median	74,300	7,508	77,669	8,385	143	3.42	1,200	1,521	4,434
Std Dev	46,675	56,317	40,805	5,837	48.7	2.19	322	186	482
N	280	290	287	253	233	231	221	225	225
Panel 5: Domestic (Chinese) Firms Post-Policy									
Mean	73,231	37,315	66,496	9,645	139	3.62	1,261	1,597	4,291
Median	66,350	13,289	64,932	9,593	136	3.20	1,200	1,495	4,375
Std Dev	32,085	96,082	27,022	4,425	41.4	1.77	267	225	438
N	436	448	446	426	398	397	375	385	386

Note: This table shows summary statistics at the model-year level. *Nominal RMB. †Maximum torque, in nanometers. †† Torque specified at a particular speed, or rotations per minute (rpm). More power at lower speed is better, so lower RPM is better.

Table 2: Domestic Firm Ownership Matrix

Panel 1: Characteristic Correlation Matrix

	Sales volume	Torque	Horsepower	Weight	Height	Length
Price	-0.13	0.51	0.54	0.67	0.02	0.58
Sales volume	1.00	-0.12	-0.12	-0.14	0.00	-0.06
Torque		1.00	0.96	0.54	0.12	0.45
Horsepower			1.00	0.51	0.05	0.46
Weight				1.00	0.40	0.79
Height					1.00	0.02

Panel 2: 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: Panel 1 shows correlations between characteristics (at the model-year level). Units are as in Table 1. Panel 2 shows 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 3: Fuel Economy Policy Impact on Domestic Firms

Panel 1: Baseline Specification

Dependent Variable:	I. Log Torque (nm)	II. Log Price (nm)	III. Weight (kg)	Model f.e.	Firm & class f.e.	Class f.e.
					Log Torque (nm)	
				IV.	V.	VI.
$\text{Policy}_t \cdot \text{Domestic}_j$	**-.1****	**-.1****	**-60***	**-.065****	**-.082***	**-.11***
	(.049)	(.048)	(31)	(.026)	(.049)	(.055)
Policy_t	.035	.016	29**	.025	.03	.04*
	(.022)	(.022)	(13)	(.018)	(.022)	(.023)
Domestic_j	-.085	-.7***	-55	-.065	-.14	-.18**
	(.12)	(.15)	(65)	(.047)	(.11)	(.086)
Firm f.e.	Y	Y	Y	N	Y	N
Model f.e.	N	N	N	Y	N	N
Class f.e.	N	N	N	N	Y	Y
N	1643	1653	1599	1643	1643	1643
R^2	0.07	0.42	0.06	0.9	0.27	.14

Panel 2: Conditional on sales

				All years (2002-2013)		
Dependent Variable:	I. Log Torque (nm)	II. Log Price (nm)	III. Weight (kg)	IV. Log Torque (nm)	V. Log Price (nm)	VI. Weight (kg)
$\text{Policy}_t \cdot \text{Domestic}_j$	**-.096***	**-.094***	**-56***	**-.11***	**-.17****	**-87****
	(.05)	(.051)	(31)	(.061)	(.072)	(42)
Policy_t	.043*	.029	35***	.12***	-.0074	88***
	(.022)	(.023)	(13)	(.024)	(.028)	(16)
Domestic_j	-.078	-.68***	-47	-.12	-.62***	-41
	(.12)	(.15)	(64)	(.091)	(.14)	(61)
Sales Volume_i	-9.6e-07***	-1.4e-06***	-.00069***	-7.0e-07***	-1.3e-06***	-.00062***
	(3.2e-07)	(4.4e-07)	(.00024)	(2.6e-07)	(3.9e-07)	(.00019)
Firm f.e.	Y	Y	Y	Y	Y	Y
N	1643	1653	1599	2030	2060	1984
R^2	0.13	0.46	0.1	0.16	0.47	0.08

Note: This table reports difference-in-differences regression estimates of the effect of the 2009 fuel economy standards on domestic firms at the model-year level (e.g., an observation is the 2010 VW Jetta). Estimates are variants of:

$$Y_{it} = \alpha + \beta\left(\text{Policy}_t \cdot \text{Domestic}_j\right) + \gamma_1 \text{Policy}_t + \gamma_2 \text{Domestic}_j + \gamma_3 \text{Sales Volume}_i + (\mathbf{1} \mid \text{Firm/Model/Class} = j/i/k) + \varepsilon_{ijt}$$

Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. Policy_t is 1 if the year is 2009-11, and 0 if 2006-08. Sales volume is the number of units sold. In the "all years" specifications I require models to have sales vol of at least 5,000. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 4: Fuel Economy Policy Impact on Domestic Firms (Sample Split by Firm Type)

Panel 1: Dependent Variable = Log Torque (nm)

Sample:	I. Firms with JVs	II. SOEs	III. SOEs without JVs	IV. Private	V. Private without JVs
$\text{Policy}_t \cdot \text{Domestic}_j$	**-.15****	**-.12****	**-.12****	**-.082**	**-.037**
	(.068)	(.051)	(.048)	(.085)	(.1)
Two individual effects & firm f.e.	Y	Y	Y	Y	Y
N	1293	1377	1154	1281	1226
R^2	0.1	0.6	0.1	0.1	0.07

Panel 2: Dependent Variable = Log Price (RMB)

Sample:	I. Firms with JVs	II. SOEs	III. SOEs without JVs	IV. Private	V. Private without JVs
$\text{Policy}_t \cdot \text{Domestic}_j$	**-.17****	**-.16*****	**-.14****	**-.035**	**.013**
	(.07)	(.058)	(.06)	(.071)	(.076)
Two individual effects & firm f.e.	Y	Y	Y	Y	Y
N	1303	1388	1166	1294	1242
R^2	0.42	0.42	0.34	0.41	0.4

Panel 3: Dependent Variable = Weight (kg)

Sample:	I. Firms with JVs	II. SOEs	III. SOEs without JVs	IV. Private	V. Private without JVs
$\text{Policy}_t \cdot \text{Domestic}_j$	**-94*****	**-69****	**-56**	**-55**	**-30**
	(30)	(28)	(54)	(58)	(70)
Two individual effects & firm f.e.	Y	Y	Y	Y	Y
N	1263	1345	1135	1257	1207
R^2	0.07	0.01	0.01	0.06	0.05

Note: This table reports difference-in-differences regression estimates of the effect of the 2009 fuel economy standards on domestic firms at the model-year level (e.g., an observation is the 2010 VW Jetta). Estimates are variants of:

$$\begin{aligned} Y_{it} &= \alpha + \beta\,(\text{Policy}_t \cdot \text{Domestic}_j) + \gamma_1 \text{Policy}_t + \gamma_2 \text{Domestic}_j + \gamma_3 \text{Sales Volume}_i \\ &\quad + (\mathbf{1} \mid \text{Firm/Model/Class} = j/i/k) + \varepsilon_{ijt} \end{aligned}$$

Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. Policy_t is 1 if the year is 2009-11, and 0 if 2006-08. Sales volume is the number of units sold. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 5: Fuel Economy Policy Impact on Domestic Firms (Firm Type Interactions)

Panel 1: Baseline Specification

Dependent Variable:	I. Log Torque	II. Log Price	III. Weight
$\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV}$	**-.16***	**-.2*****	**-111***
	(.083)	(.052)	(65)
$\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{SOE}_j$	**-.045**	**-.019**	**-24**
	(.063)	(.056)	(41)
$\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j$	**.12**	**.12**	**102**
	(.095)	(.088)	(66)
$\text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j$	-.14	-.26	-259**
	(.23)	(.22)	(124)
Domestic-Policy & 4 individual effects	Y	Y	Y
Firm & class f.e.	Y	Y	Y
N	1643	1653	1599
R^2	0.34	0.42	0.28

Panel 2: Conditional on sales

Dependent Variable:	I. Log Torque	II. Log Price	III. Weight
$\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV}$	**-.16***	**-.2*****	**-105**
	(.086)	(.06)	(76)
$\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{SOE}_j$	**-.072**	**-.049**	**-44**
	(.067)	(.06)	(46)
$\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j$	**.13**	**.12**	**90**
	(.097)	(.089)	(70)
$\text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j$	-.09	-.19	-200
	(.26)	(.21)	(170)
Sale Volume_i	-9.7e-07***	-1.4e-06***	-.00069***
	(3.2e-07)	(4.4e-07)	(.00024)
Domestic-Policy & 4 individual effects	Y	Y	Y
Firm & class f.e.	Y	Y	Y
N	1643	1653	1599
R^2	0.12	0.45	0.1

Note: This table reports difference-in-differences regression estimates of the effect of the 2009 fuel economy standards on domestic firms at the model-year level. Estimates are variants of:

$$\begin{aligned} Y_{it} &= \alpha + \beta_1 (\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j) + \beta_2 (\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV}_j) \\ &+\beta_3 (\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{SOE}_j) + \beta_4 (\text{Policy}_t \cdot \text{Domestic}_j) + \gamma_1 \text{Policy}_t + \gamma_2 \text{Domestic}_j + \text{Has JV}_j + \text{SOE}_j \\ &+\gamma_3 \text{Sales Volume}_i + (\mathbf{1} \mid \text{Firm/Model/Class} = j/i/k) + \varepsilon_{ijt} \end{aligned}$$

Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. Policy_t is 1 if the year is 2009-11, and 0 if 2006-08. Sales volume is the number of units sold. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 6: Fuel Economy Policy Impact on Domestic Firms (Sample Split by Firm Competition with Foreign Partner)

Panel 1: Domestic and Foreign Partners both Produced Primarily SUVs Prior to Policy

Dependent Variable:	I. Log Torque	II. Log Price	III. Weight
$\text{Policy}_t \cdot \text{Domestic}_j$	**-.23****	**-.16**	**-172*****
	(.082)	(.098)	(55)
Policy_t	.032	.041	32
	(.037)	(.034)	(26)
Domestic_j	.27	-.62***	132
	(.16)	(.17)	(93)
Sales Volume_i	-1.3e-06***	-1.3e-06***	-.00083***
	(4.1e-07)	(4.1e-07)	(.00029)
Firm f.e.	N	N	N
N	566	574	555
R^2	.092	.37	.083

Panel 2: Domestic and Foreign Partners both Produced Primarily Minivans Prior to Policy

Dependent Variable:	I. Log Torque	II. Log Price	III. Weight
$\text{Policy}_t \cdot \text{Domestic}_j$	**-.16*****	**-.15*****	**-99****
	(.059)	(.058)	(42)
Policy_t	.049*	.036	34**
	(.03)	(.028)	(15)
Domestic_j	-.15	-.72***	-72
	(.12)	(.15)	(104)
Sales Volume_i	-1.2e-06***	-2.0e-06***	-.00088***
	(3.0e-07)	(4.1e-07)	(.0003)
Firm f.e.	Y	Y	Y
N	856	864	837
R^2	0.2	0.61	0.13

Note: This table reports difference-in-differences regression estimates of the effect of the 2009 fuel economy standards on domestic firms at the model-year level (e.g., an observation is the 2010 VW Jetta). Estimates are variants of:

$$\begin{aligned} Y_{it} &= \alpha + \beta\,(\text{Policy}_t \cdot \text{Domestic}_j) + \gamma_1 \text{Policy}_t + \gamma_2 \text{Domestic}_j + \gamma_3 \text{Sales Volume}_i \\ &\quad + (\mathbf{1} \mid \text{Firm/Model/Class} = j/i/k) + \varepsilon_{ijt} \end{aligned}$$

Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. Only domestic and foreign firms that have a JV, and for which the partner produces a similar distribution of vehicle class, are included. Policy_t is 1 if the year is 2009-11, and 0 if 2006-08. Sales volume is the number of units sold. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 7: Fuel Economy Policy Impact on Domestic Firms (Triple-Differences)

	With firm f.e.			Without firm f.e.		
Dependent Variable:	I. Log Torque	II. Log Price	III. Weight	IV. Log Torque	V. Log Price	VI. Weight
$\text{Policy}_t^{2008} \cdot \text{Domestic}_j \cdot \text{Continuing}_i$	**.077***	**.25****	**133****	**.19****	**.22***	**143****
	(.025)	(.027)	(29)	(.02)	(.066)	(21)
$\text{Policy}_t^{2008} \cdot \text{Domestic}_j$	-.098**	-.19**	-131*	-.2***	-.19*	-137**
	(.017)	(.024)	(31)	(.015)	(.057)	(26)
$\text{Domestic}_j \cdot \text{Continuing}_i$	.056*	-.1**	-59	-.02	-.012	-65*
	(.014)	(.019)	(29)	(.02)	(.066)	(21)
$\text{Policy}_t^{2008} \cdot \text{Continuing}_i$	-.0086	-.06	-4.5	.015	.029***	25
	(.03)	(.031)	(5.6)	(.012)	(.0015)	(34)
Policy_t^{2008}	.024*	.04	11	.018*	.0086	-11
	(.0065)	(.026)	(7.6)	(.0053)	(.008)	(36)
Domestic_j	.61***	.3***	271***	-.13**	-.67***	-3.3
	(.015)	(.023)	(2.6)	(.014)	(.057)	(26)
Continuing_i	-.06	.031	37*	-.064**	-.046***	-2
	(.038)	(.028)	(12)	(.0093)	(.003)	(35)
Sales Volume_i	-1e-06**	-2e-06*	-.0012**	-2e-06***	-2e-06**	-.0012***
	(2e-07)	(6e-07)	(.00025)	(2e-07)	(3e-07)	(.00011)
Firm f.e.	Y	Y	Y	N	N	N
N	636	646	626	636	646	626
R^2	.58	.69	.56	.08	.29	.047

Note: This table reports difference-in-differences regression estimates of the effect of the 2009 fuel economy standards on domestic firms at the model-year level (e.g., an observation is the 2010 VW Jetta). Estimates are variants of:

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

Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. Policy_t is 1 if the year is 2009-11, and 0 if 2006-08. Sales volume is the number of units sold. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 8: Key Robustness Tests using Torque (Part 1)

Panel 1

Dependent Variable: Log torque	Individual effects		Fixed Effects		Sales vol≥ 5,000 units
	I.	II.	III.	IV.	V.
$\text{Policy}_t \cdot \text{Domestic}_j$	**-.07***		**-.13****	**-.093***	**-.11****
	(.042)		(.058)	(.051)	(.047)
Policy_t		-.00013	.045*	.058*	.057***
		(.023)	(.024)	(.031)	(.021)
Domestic_j		-.15	-.15	.82***	-.14
		(.11)	(.094)	(.021)	(.095)
Firm f.e.	Y	Y	N	Y	Y
Year f.e.	N	N	N	Y	N
N	1643	1643	1643	1643	1176
R^2	0.07	0.07	.071	.5	0.07

Panel 2

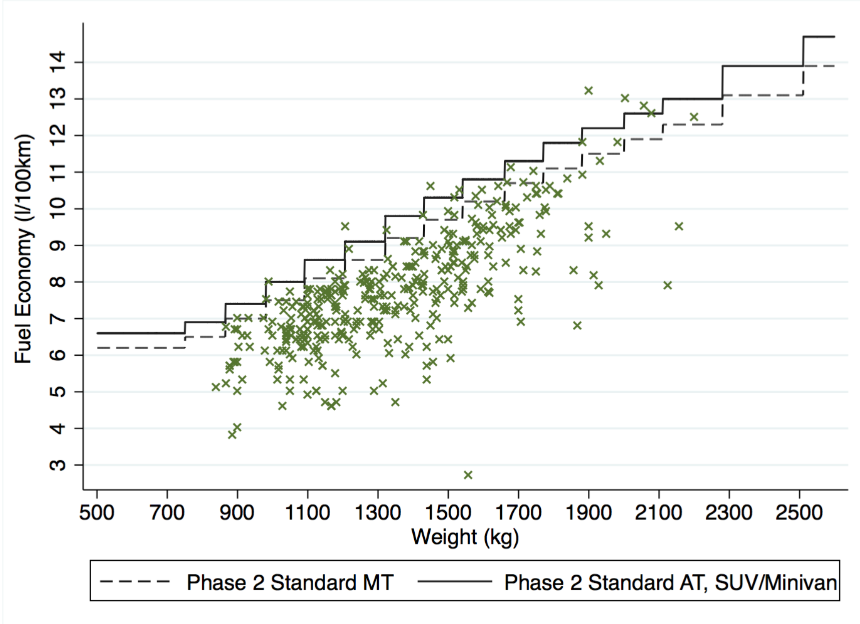
	Standard error clustering			Placebo test with artificial policy in year:	
Dependent Variable: Log torque	I. Brand-year	II. Robust	III. Two-way brand year (Cameron-Gelbach-Miller)	IV. 2006	V. 2007
$\text{Policy}_t \cdot \text{Domestic}_j$	**-.094*****	**-.1****	**-.094****	**.025**	**-.059**
	(.028)	(.049)	(.042)	(.052)	(.045)
Policy_t	.036**	.035	.036**	.027	.032
	(.015)	(.022)	(.018)	(.03)	(.02)
Domestic_j	.83***	-.085	.83***	-.14	-.11
	(.065)	(.12)	(.025)	(.11)	(.11)
Firm f.e.	Y	Y	Y	Y	Y
N	1643	1643	1643	824	1051
R^2	.5	0.08	.5	0.08	0.07

Note: This table reports difference-in-differences regression estimates of the effect of the 2009 fuel economy standards on domestic firms at the model-year level (e.g., an observation is the 2010 VW Jetta). Estimates are variants of:

$$\begin{aligned} Y_{it} &= \alpha + \beta\left(\text{Policy}_t \cdot \text{Domestic}_j\right) + \gamma_1 \text{Policy}_t + \gamma_2 \text{Domestic}_j + \gamma_3 \text{Sales Volume}_i \\ &\quad + (\mathbf{1} \mid \text{Firm/Model/Class} = j/i/k) + \varepsilon_{ijt} \end{aligned}$$

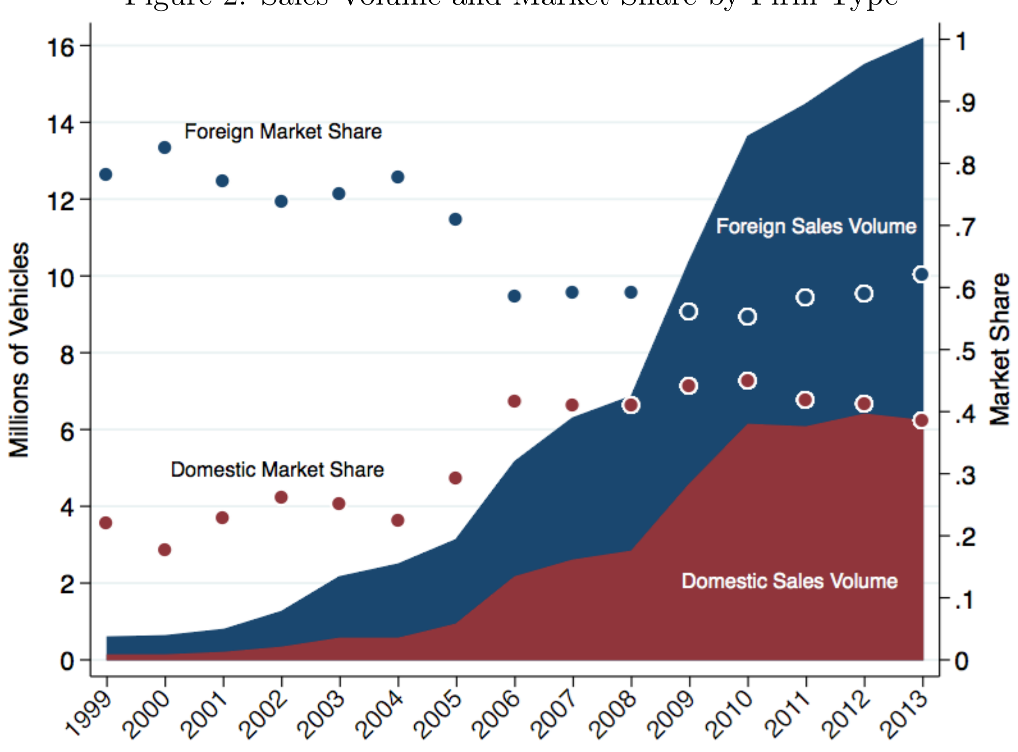
Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. Policy_t is 1 if the year is 2009-11, and 0 if 2006-08. Sales volume is the number of units sold. Standard errors are robust and clustered by firm, except where specified. *** indicates $p < .01$.

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



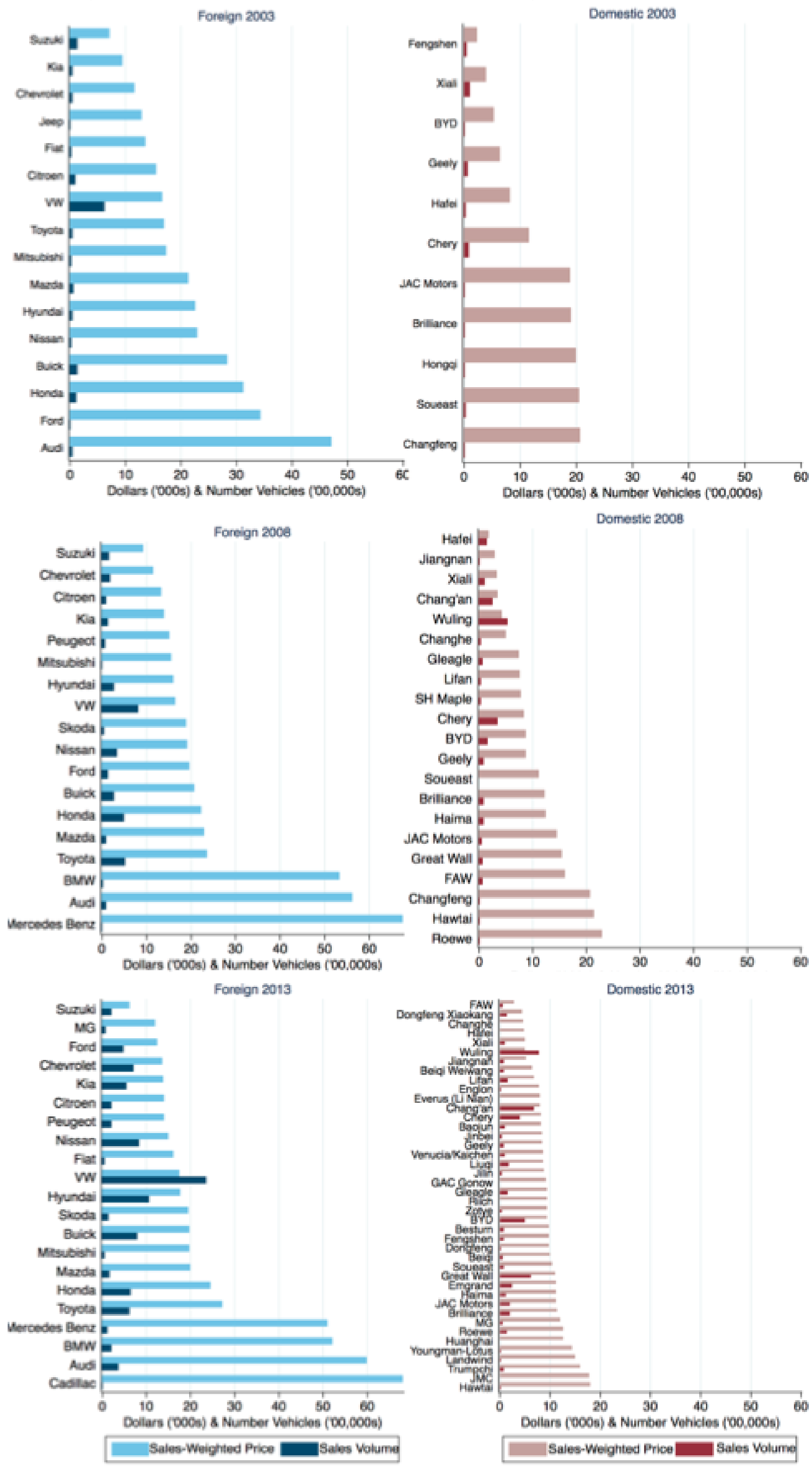
Note: This figure shows China's 2009 Phase 2 fuel economy standards. Dotted line is for manual transmission, line is for automatic and all SUVs/minivans.

Figure 2: Sales Volume and Market Share by Firm Type



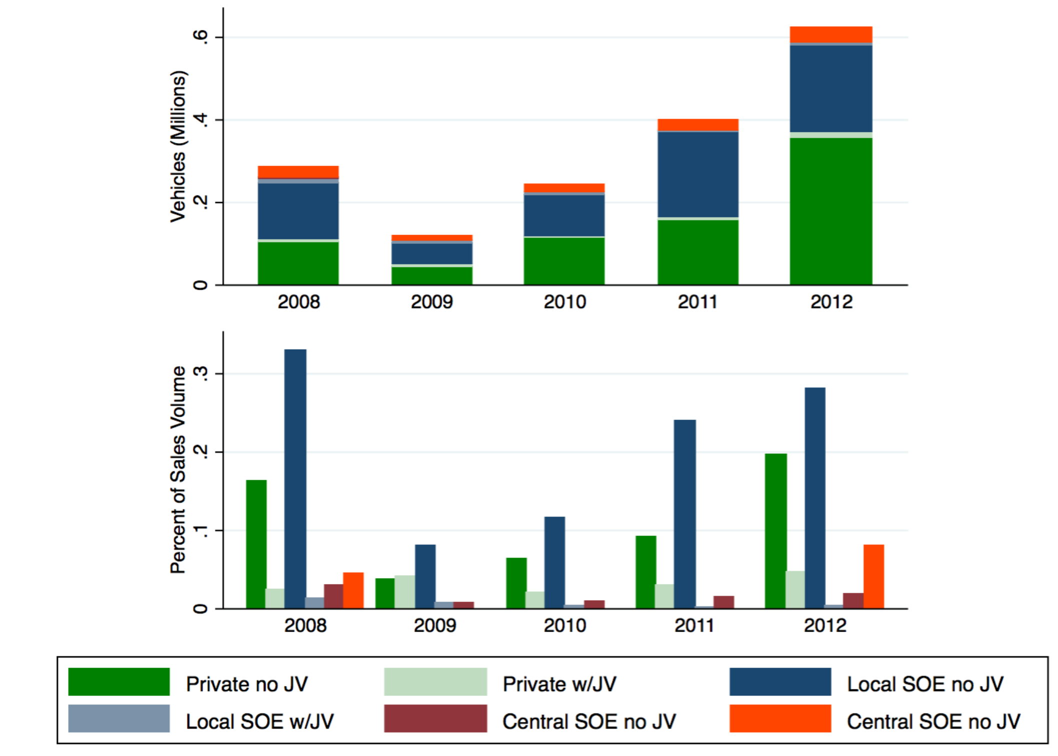
Note: This figure shows foreign and domestic brand Chinese sales volume (number of new vehicles sold in a given year) on the left axis, where the blue area is foreign and the red area is domestic. Market share of sales volume is on the right axis and in the foreign (blue) and domestic (red) scatterplot.

Figure 3: Sales Volume and Sales-Weighted Price by Firm



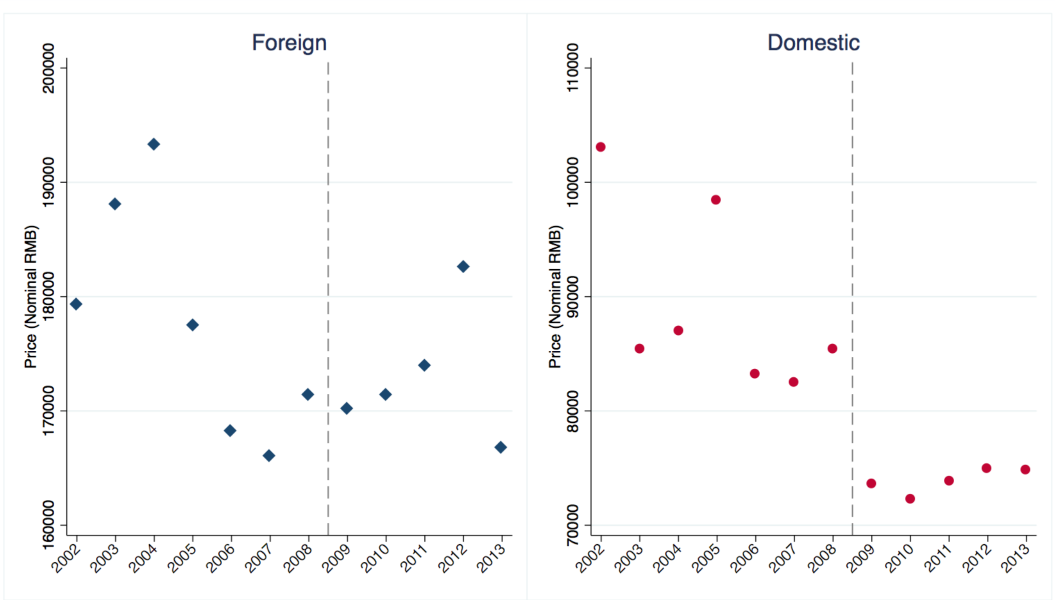
Note: This figure shows firm sales volume (number of vehicles) and sales-weighted average price across models sold.

Figure 4: Domestic Firm Export Volume and Percent of Total Sales Volume 2008-2012



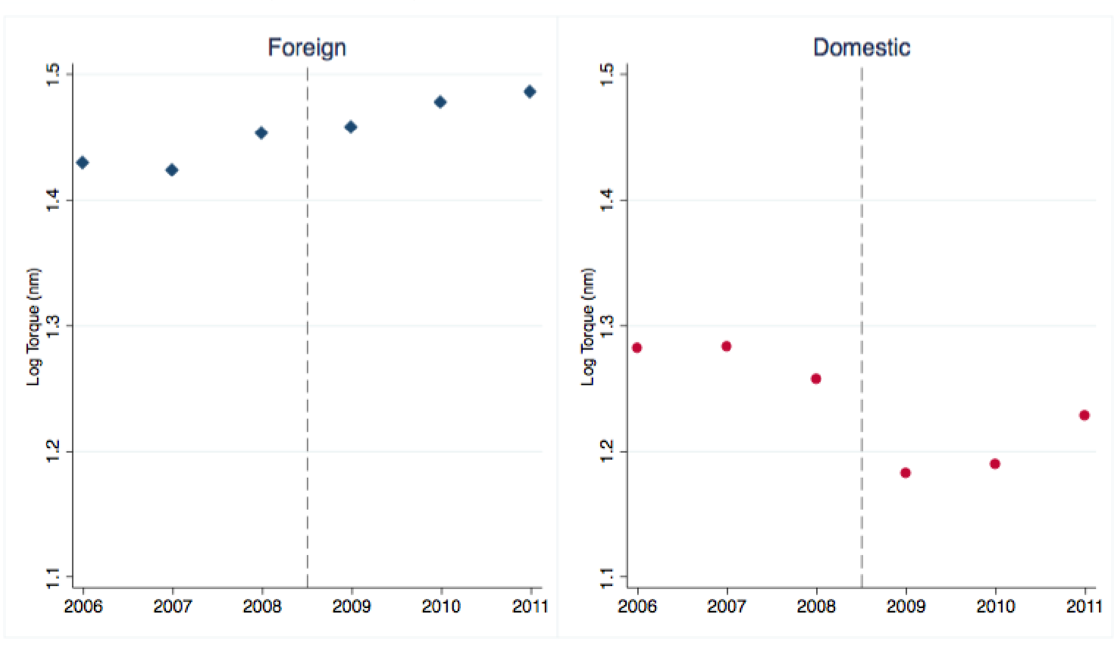
Note: This figure shows Chinese domestic firm vehicle exports. Top: exports by ownership type. Bottom: exported fraction of total sales volume. For example, the first green bar in the bottom graph is exports divided by all vehicles sold among all firms that are privately owned and have no JV.

Figure 5: Price by Firm Type, 2002-2013



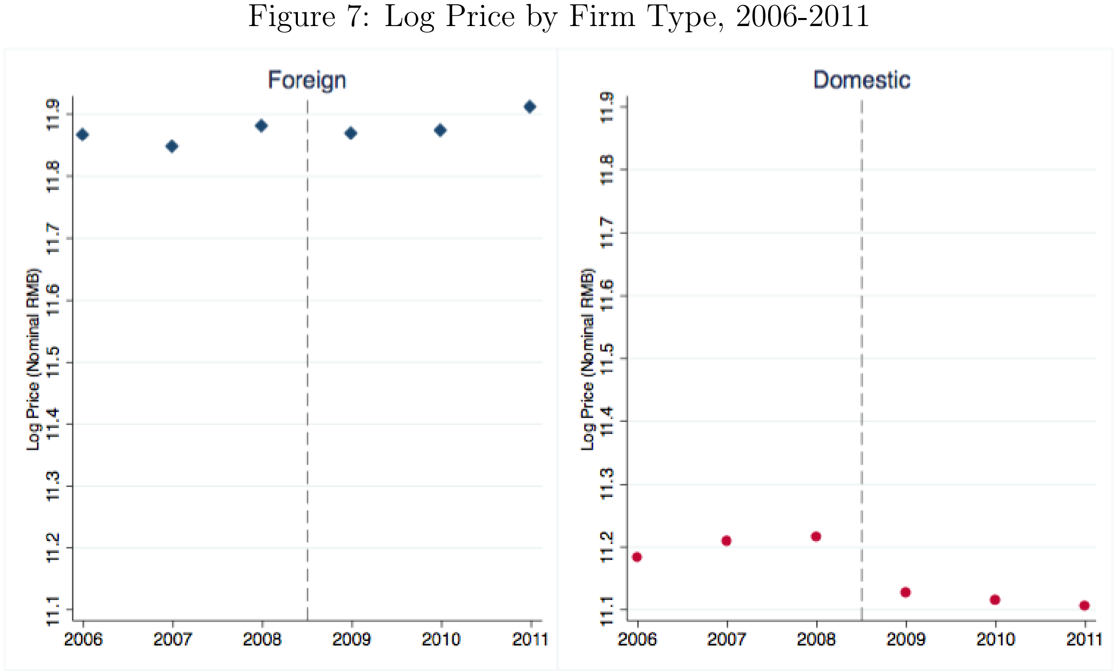
Note: This figure shows sales-weighted torque and price by firm type. Average taken across firms of each firm's average sales weighted characteristic.

Figure 6: Log Torque by Firm Type, 2006-2011



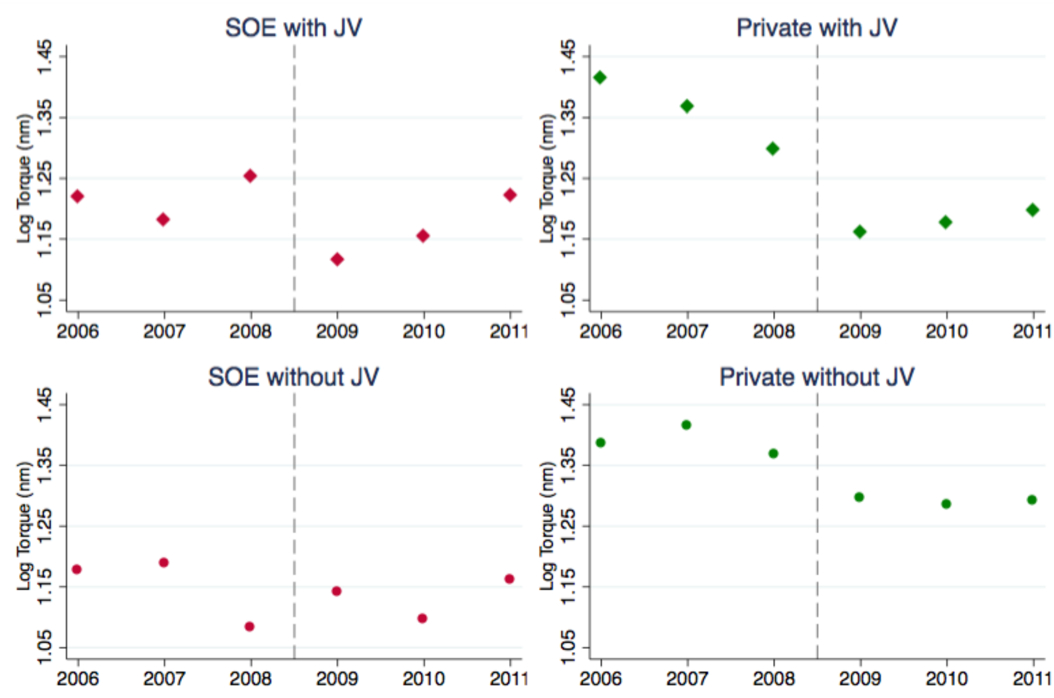
Note: This figure shows sales-weighted torque and price by firm type. Average taken across firms of each firm's average sales weighted characteristic.

Figure 7: Log Price by Firm Type, 2006-2011



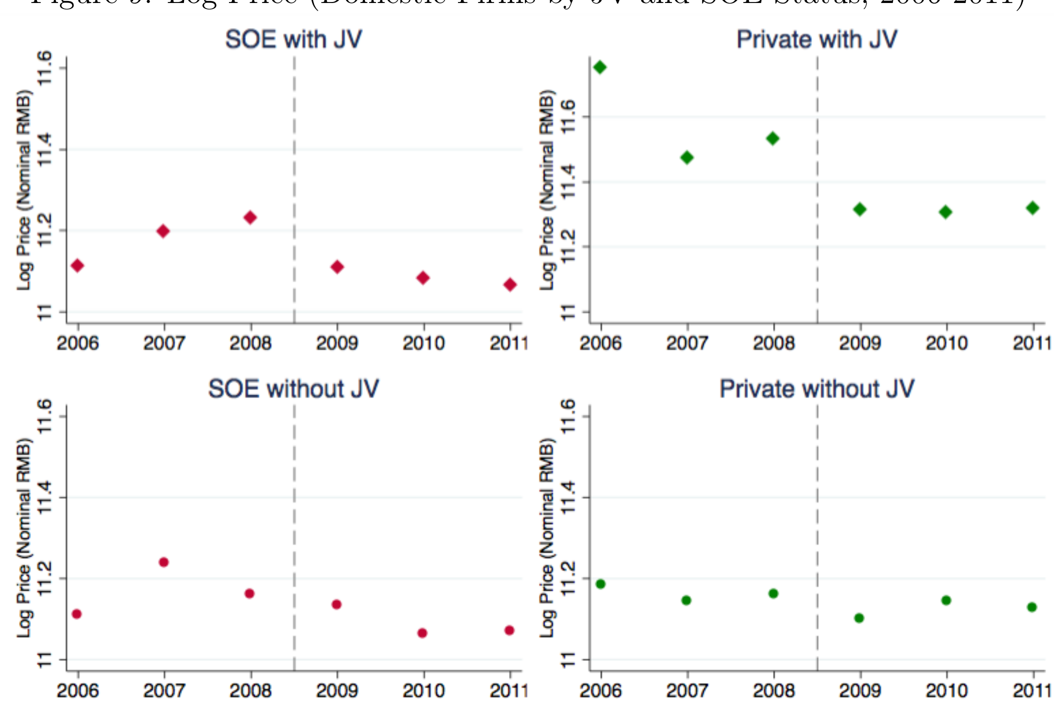
Note: This figure shows sales-weighted torque and price by firm type. Average taken across firms of each firm's average sales weighted characteristic.

Figure 8: Log Torque (Domestic Firms by JV and SOE Status, 2006-2011)



Note: This figure shows sales-weighted torque and price by firm type. Average taken across firms of each firm's average sales weighted characteristic.

Figure 9: Log Price (Domestic Firms by JV and SOE Status, 2006-2011)



Note: This figure shows sales-weighted torque and price by firm type. Average taken across firms of each firm's average sales weighted characteristic.

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