Joint Ventures and Technology Adoption:

A Chinese Industrial Policy that Backfired

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Abstract

Technology transfer from foreign firms has been important to economic growth in developing countries. To spur it, emerging market policymakers often mandate joint ventures (JVs) between foreign and domestic firms. Through knowledge spillovers, JVs should reduce the cost of technology acquisition for domestic firms. Yet domestic firm rents from JVs lead to a cannibalization effect that discourages innovation. Which of these opposing forces dominates is an empirical question. I address it with novel data on China's auto sector. Recent fuel economy standards provide plausibly exogenous variation in the fixed cost of producing powerful, heavy vehicles, which are associated with quality and higher profit margins. The standards required domestic firms to invest in technology upgrading to maintain or improve quality. Foreign firms already possessed the technology. In a difference-in-differences design, I show that relative to foreign firms, domestic firms reduced quality and price in response to the standards. Domestic firms with JVs reduced quality the most. This negative JV effect is larger than the negative state ownership effect. JVs can lead domestic firms down the manufacturing quality ladder, helping to reconcile FDI's positive role in the endogenous growth literature with mixed empirical findings at the country level.
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China's policy of requiring all foreign car makers to form local joint ventures is "like opium" for Chinese firms and is failing to foster world-class indigenous automakers, a former minister was quoted as saying...[He said,] "so many years have passed and we don't even have one brand that can be competitive in the auto world."
– Reuters (2012) quoting He Guangyan, Former Chinese Minister of Machinery & Industry.

1 Introduction

Important technologies have historically originated in developed countries and trickled down to lagging countries (Comin and Hobijn 2004). To hasten this process, many emerging market governments encourage technology transfer from advanced foreign firms to backward local firms. I explore how an industrial policy designed to induce technology transfer perversely disincentivized technology acquisition. To my knowledge, this paper is the first quasi-experimental evaluation of an industrial policy's effect on firm technology acquisition in an emerging market.

Developing countries often require foreign entrants to form joint ventures (JVs) with domestic firms. They hope the JVs will increase domestic partners' access to foreign R&D and manufacturing processes, reducing the cost of technology acquisition. JVs have a second important feature: the domestic partner receives a share of foreign brand profits. I show how these two features affect the domestic partner's innovation incentives in a stylized model. First, in an adaptation of the Gilbert and Newbery (1982) efficiency effect, the JV reduces the cost of technology acquisition. Pushing in the opposite direction is a cannibalization channel, similar in spirit to the Arrow (1962) replacement effect, which deters monopolists from innovating. The threat of cannibalizing rents from foreign partner sales discourages the domestic firm from investing in substitutes to its partner's products. These countervailing forces exist independently of the foreign partner's technology transfer behavior.

How JVs impact innovation is relevant to policy in many countries; for example, Brazil, Mexico, India, Nigeria, and Malaysia have employed JV mandates.[1] As a case study,

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

I focus on China's automotive industrial policy, which has called for globally competitive, high-quality Chinese firms since the late 1970s.[2] The policy's cornerstone is a mandate that foreign entrants produce via JVs with domestic firms. High tariffs precluded large-scale imports, so foreign brands must establish JVs in order to access China's market.

The following example illustrates the JV structure during the period I study, from 1999 to 2013. Ford manufactures in China through two JVs. The larger is with Chang'an Automobile group. The Chang'an Ford JV plants produce only Ford vehicles. Chang'an helped finance the JV plants and receives fifty percent of their profits. Chang'an produces its own brands at other plants without Ford involvement. Foreign brands like Ford, Volkswagen, and Toyota have consistently dominated China's market in quality, price, and market share. Chinese firm exports have been negligible. 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. In this paper, I evaluate whether the JV mandate achieved the explicit government objective of technology acquisition and upgrading among domestic firms.

China's sudden and stringent 2009 fuel economy standards provide plausibly exogenous variation in the fixed cost of technology upgrading.[3] Standards compel more advanced technology in the heavy, powerful vehicles that garner the highest profit margins. An automaker facing fuel economy standards can either augment fuel efficiency technologies or reduce quality. The fuel economy policy imposed a fixed cost disadvantage on domestic firms. Foreign firms like Ford, which already faced such standards elsewhere, incurred only the variable cost of including their efficiency technologies in local production.

I use a difference-in-differences design with novel, reliable, comprehensive model-level sales and characteristics data for the Chinese auto market. Three product attributes - torque (acceleration), price, and weight - in combination are well-established as measures of qual-

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

[3]China imposed fuel economy standards in phases from 2005-2009, but binding standards came into force in 2009 (see Section 5).

ity in the automotive sector.[4] I also use a discrete choice framework - the representative consumer logit (RCL) model - to measure quality as the residual from an instrumented regression of market shares on price. Product attributes offer an alternative to the conventional measures used in the literature, such as accounting-based productivity functions, R&D investment, and patents. These are more opaque measures, only distantly connected to the firm's actual products. More importantly, they are of little use in China, in part due to different patenting and data collection cultures.

I show that while foreign firms continued on an upward trajectory, China's standards led domestic firms to reduce quality and price, without gaining market share. Variation is within firm, and foreign firms are treated as the "control" in most specifications. A key assumption is that foreign firm technology transfer behavior did not change immediately around the policy. Relative to foreign firms, the policy reduced domestic model price by 15%, torque by 11%, weight by 5%, and RCL quality by 60%. I confirm the main result in a triple-differences design exploiting the standards' staged implementation in 2008 and 2009 for new and continuing models. I conduct a rich array of robustness tests, including placebo tests, alternative time spans around the policy, and varying fixed effects. I also demonstrate pre-policy parallel trends across firm types.

I disaggregate the standards' impact along two dimensions: whether the domestic firm has a JV, and whether it is a state-owned enterprise (SOE). The negative effect is strongest for firms with JVs. It is present but smaller for SOEs without JVs, and insignificant for private firms. Although few firms are SOEs without JVs or private with JVs, I establish significance across effects in specifications that interact the policy with firm status. The policy's effect is 16-18% larger among firms with JVs than among SOEs. This analysis assumes that changes in model attributes across domestic firms with and without JVs would have been the same after relative to before the change, had the policy not occurred.

If a cannibalization threat disincentivizes innovation, the effect should be larger among domestic firms that compete more intensively with their partner. This concept is similar to

[4]See Section 4 for details and references.

the diversion ratio in merger analysis of differentiated products, as in Shapiro (1996). Indeed, I show that the policy had much stronger negative effects on domestic firms that operated in similar price segments or vehicle classes as their foreign JV partners prior to the policy. In sum, the negative effect of increasing own quality on the share of JV profits appears to outweigh any advantage from knowledge spillovers.

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 increase technology upgrading (and thereby export capacity) among domestic firms. I find that both had precisely the opposite effect. This contrasts with the government's intentions. My findings are consistent with the literature documenting that (a) private firms are more productive than SOEs in China; and (b) JVs are negatively correlated with technology diffusion.[5]

This analysis is limited in scope. The JV mandate's welfare effects are much broader than the quality metrics I examine; there may be benefits along employment, brand variety, and government revenue dimensions. I also cannot assess whether the post-fuel economy policy decision to go down-market was profit maximizing. This paper argues that the JV policy "failed" *only* from the perspective of the government's explicit goals that the JV mandate encourage domestic firm innovation. Further, my analysis addresses short term responses to a technology cost shock. In the longer term, domestic Chinese firms may reach the global technology frontier; my results suggest these will likely be private firms without JVs. Finally, my empirical results may not generalize to voluntary JVs or those in which partners have similar technical capacity. However, the cannibalization channel that I propose may exist in JVs more broadly, and my results do indicate the difficulty of contracting knowledge spillovers.

Despite these limitations, this paper contributes to our understanding of government's

[5] On (a), see Lin, Liu and Zhang (1998); Allen et al. (2005); Khandelwal, Schott, and Wei (2013); Chen, Jiang, and Ljungqvist (2015); and Fang and Lerner (2015). On (b), see Ramachandran (1993); Urata and Kawai (2000); and Moran (2002). However, other studies find evidence of positive spillovers from JVs, like Dimelis and Louri (2002) and Javorcik (2004).

mediating role in technology diffusion, which is central to economic development (Young 1991; Lucas 1993). A story in which JVs lead domestic firms *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.[6] More broadly, my results speak to a 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). Conversely, new institutional economists attribute the success of East Asian "Tigers" to government direction (Rodrik, Subramanian, and Trebbi 2004; Amsden 1989). In my setting, the most innovative firms are the least touched by industrial policy.

While I do not estimate a counterfactual to the JV mandate, China could clearly have pursued alternatives. 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 or Lenovo. A second path is Japan and Korea's combination of infant industry protection, foreign technology licensing, and reverse engineering. This path is more difficult under modern trade law, but China arguably pursued it successfully in internet services, where protectionism combined with freewheeling competition among privately owned startups produced Tencent, Baidu, and Alibaba.

Despite a rich theoretical literature, it has been challenging to evaluate the efficacy of industrial policies that target technology upgrading.[7] I depart from much of the past literature by using technical quality. Firm-level panel data are also relatively rare in the literature on technological capacity and innovation, which has relied on aggregates, case studies or

[6] On industrial policy broadly, see Grossman and Helpman (1994); Nunn and Trefler (2010); and Arnold and Javorcik (2009). On FDI, Borensztein et al. (1998) and Haskel, Pereira and Slaughter (2007) find positive effects, while Carcovik and Levine (2005); Haddad and Harrison (1993); and Konings (2001) do not. See Hale and Long (2011 and 2012) for a review. The literature on JVs finds positive effects (Lyles and Salk 1996; 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).

[7] 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.

cross-sectional survey data, particularly for the developing world (Fagerberg, Srholec and Verspagen 2010; Figueiredo 2006). This paper is related to the literatures on inefficiencies in China's industrial structure (Hsieh and Klenow 2009; Khandelwal, Schott and Wei 2011), the effects of FDI and trade on competition (Bloom, Draca and Van Reenen 2015, Aitken and Harrison 1999; Blalock and Gertler 2007), and evaluations of subsidy programs (Rotemberg 2015; Howell 2016).[8]

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 data in Section 4, and the empirical strategy data in Section 5. The results are in Section 6, and robustness tests in Section 7.

2 China's JV Policy and 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.[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). Beijing permitted FDI in automobile manufacture only via partnerships with domestic firms, which were supposed to evolve into globally competitive multinationals (State Council 2006). High tariffs historically precluded imports (see Appendix Figure 1), so a JV was the door to China's market for a foreign firm.[10]

[8]This paper is more distantly connected to the literature on attribute-based regulation (e.g. Aldy and Houde 2015; Ito and Sallee 2015).

[9]The 1986 7th Five-Year Plan 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" (Chu 2011).

[10]Tariffs were 180-220% through 1994, 70-150% through 2001, 30% through 2005, and 25% thereafter. Figure A1 shows that before 2010, less than 0.5 million vehicles were imported. Imports have since risen (mostly SUVs) to about 1 million. The protected environment enabled high markups. Deng and Ma (2010)

The JV is a stand-alone enterprise producing only foreign brand cars, and the foreign firm designs, controls, and operates the plant.[11] The foreign firm owns no more than 50%, and usually also retains 50% of profits. Beyond the even profit split, there is no public information about contractual relationships. The government initially handpicked domestic partners, but after WTO accession in 2001 retreated to approving JVs (Richet and Ruet 2008). Between 2000 and 2013, the number of foreign firms producing in China through JVs increased from four to 17. Many large Chinese firms now have multiple JVs with different foreign firms. Following WTO accession, the government removed barriers to entry for private firms. As in other sectors, SOEs were corporatized, largely separated from direct government control, and often partially listed on stock exchanges (Andrews-Speed 2012). Today, domestic Chinese auto manufacturers exist along two axes: whether or not they are majority state-owned, and whether or not they have JVs with foreign firms.

In negotiations to establish initial JVs, foreign firms benefited from information asymmetry about auto manufacturing. They sought to bound potential technology transfer by initially producing only outdated models in China, by keeping high end part production overseas, and through other, less observable ways (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).[12] The 1994 directive and similar policies were unenforceable. Instead, competition compelled foreign firms to produce the latest models in China by the mid-2000s.

Though the balance of power shifted over time, incomplete contracting and moral hazard continued to bedevil implementation of the JV arrangements (Thun 2004). For example, most GM-branded models initially chosen for China were Daewoo or Opel designs, distancing GM's China operation from Detroit's state-of-the-art. Though GM marketed itself as a purveyor of useful technology, its China research center was largely used to tweak

estimate that between 1995 and 2001, Volkswagen had a 41% market share and markups of 42%.

[11] This applies to the period I study, from 1999-2013. In recent years, some JVs have produced new, joint brands.

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

existing models for the Chinese market (Tang 2012). Foreign firm behavior is not the focus of this paper, but it appears consistent with Branstetter and Saggi (2011), who theorize that stronger intellectual property rights reduce imitation risk, increasing FDI and innovation incentives.

Beijing has consistently called for "self-reliant Chinese car manufacturers who rank among the 500 largest global firms" (NDRC 2004). Yet foreign brands dominate China's passenger vehicle market in terms of quality, price, and market share (see Figures 1-2 and Table 1). Domestic firms produce low quality, low price models. 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. There is ample anecdotal evidence from the popular press that JVs failed to achieve technology transfer.[13] Dunn (2012) concludes that

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

According to Liao Xionghui, the Vice President of Lifan (a private Chinese automaker),

> "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).

And Ho (2015) writes that

> "Requiring foreign carmakers to form ventures at least 50 percent-owned by a Chinese partner had an explicit goal to create three or four internationally competitive homegrown auto giants by 2010. Instead, the policy has drawn criticism for shielding state-owned carmakers from competition and robbing them of the incentive to build their own brands."

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

The literature on China's economy has focused on SOE efficiency relative to private firms.[14] However, in some high-tech sectors, SOEs have become globally competitive, dominating the domestic market and achieving meaningful exports.[15] Hsieh and Song (2015) show that in the 2000s SOEs had faster TFP growth and higher labor productivity than private firms. In 2013, Chinese companies held the following shares of global revenue by sector: appliances, 36%; construction machinery, 19%; electrical equipment, 16%; Internet services/software, 15%; railroad equipment, 41%; solar, 51%; and wind power, 20%. Chinese auto manufacturers had 8% (Woetzel et al. 2015). State ownership varies; for example, SOEs dominate railroad equipment while they are absent in Internet services/software. JVs have been most pervasive by far in the auto sector.

3 Incentives to Innovate in Joint Ventures

The JV industry structure may attenuate innovation incentives if producing substitutes to foreign partner models cannibalizes the domestic firm's share of JV profits. Consider the following stylized profit functions for domestic firms:

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

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

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 ($C_i = \mathcal{F}(\cdot, \phi_{\text{i}})$) is also increasing in

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

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

quality $\left(\frac{\partial \mathcal{F}}{\partial \phi} > 0\right)$. The first order conditions in quality are:

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

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

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 (ARE): when a competitive firm and a monopolist have 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. Suppose the fixed cost of achieving some technology quality level ϕ_i is is $F_j(\phi_i)$, so that $C_i = \mathcal{F}(\cdot,\ F_j(\phi_i))$.[17] The ARE stems from $\frac{\partial}{\partial \pi_{JV}^{foreign}}\left(\frac{\partial \pi_j}{\partial F_j}\right) < 0$ (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.[18]

Countering the ARE is what Gilbert and Newbery (1982) call the "efficiency effect." They assume the monopolist is more efficient in making profits than a duopoly, so its pre-emptive payoff is larger than the entrant's. The parallel assumption in the JV context is

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

[17] 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.

[18] 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.

that domestic firms with JVs have a lower F_j because they have greater access to foreign firm technology. Therefore, $F_{j,JV} \leq F_{j,No\ JV}$. Holding other aspects of the cost function fixed, this implies that increasing quality is at least as costly for firms without JVs as for firms with JVs, or $\frac{\partial C_{i,JV}}{\partial \phi_i} \leq \frac{\partial C_{i,No\ JV}}{\partial \phi_i}$. If the efficiency effect dominates, this will make the preemptive payoff higher, and the firm with a JV will invest more in innovation.

The fuel economy standards exogenously impose higher $F_j(\phi)$, or fixed cost for a given quality. To comply and maintain quality, domestic firms must invest this fixed cost, as well as bearing the variable cost, which I assume to be equal across firms. Foreign firms already possesses the technology, so $F_{foreign} = 0$. The theory is ambiguous about whether firms with or without JVs have a greater incentive to invest in higher ϕ_i (pay the fixed cost F_j to acquire fuel efficiency technology). It depends on whether the negative effect on ϕ of access to the foreign firm's profits (ARE) outweighs the positive effect of a lower technology acquisition cost (efficiency effect). If the former cannibalization effect dominates, then:

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

The three terms on the left are negative. The two terms on the right are positive, summing to zero with no efficiency effect. 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 $\frac{\partial \pi_{JV}^{foreign}}{\partial \phi_i}$).

If an automaker just meets the standards, its profit function contains a constraint generating a shadow cost of producing fuel inefficient vehicles. In his model of the U.S. auto sector, Jacobsen (2013) incorporates this shadow cost. Jacobsen and other structural models of fuel economy, like Bento et al. (2009), are much more complex than the present approach. Yet they treat technological change as exogenous to the competitive equilibrium. Firms respond to standards by changing prices, which shifts the vehicle mix to lower margin, more efficient models. However, multinational automakers have made large R&D investments in fuel efficiency (e.g. Knittel 2011). Unlike much of the literature on fuel economy standards, I am only interested in their relationship to technology upgrading. They require technology upgrading investment to produce a given vehicle quality level. This fixed cost is zero before the standard, and zero for foreign firms. It is an opportunity to observe whether technology upgrading is more costly among firms with or without JVs (that is, whether $\frac{\partial \phi_{i,JV}}{\partial F_{j,JV}} < \frac{\partial \phi_{i,No\ JV}}{\partial F_{j,No\ JV}}$ or vice versa).

4 Data and Descriptive Statistics

This paper is based on novel, national, model-level data of light-duty passenger vehicle sales in China between 1999 and 2013. These data are from police registration via the State Council Development Research Center, which conducts analysis for China's top-level State (i.e. not Party) governing apparatus.[19] Each observation is a new model-year, such as the 2010 Volkswagen Jetta. The data include the ultimate Original Equipment Manufacturer (OEM), brand, model name, vehicle class, engine displacement, and power train.[20]

I acquired the following new 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).[21] Descriptive statistics at the model-year level are in Table 1.[22] Figure 1 shows that sales increased from under 1 million units in 1999 to 16 million units in 2013. Variety increased as well; the number of models increased linearly from 23 in 1999 to 426 in 2012. Foreign market share declined from 80% in 1999 to 55% in

[19]Consumers (private and public) must register new vehicle purchases to the local police. I acquired these 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.

[20]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.

[21]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.

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

2009, and then increased somewhat to 61% in 2013 (these figures exclude imports).

I focus the analysis on four quality measures. First, price is a good indicator of quality in the auto market, conditional on meaningful 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). I use nominal local currency (RMB) prices to avoid issues around exchange rates (inflation is differenced out). Table 1 shows nominal RMB and dollar prices. The average price is 136,000 RMB. When weighted by sales within firm, it declines to 122,000 RMB, or almost $17,000.

Second is vehicle weight. In general, heavier cars have more amenities and are safer. The cheapest way to meet fuel economy standards, however, is to reduce weight, resulting in flimsier, smaller cars with fewer amenities. However, observing a change in weight alone is insufficient, because automakers also substitute advanced lightweight materials, like aluminum and carbon fiber, for steel. Vehicle torque, responsible for acceleration and power, is the third quality measure.[23] Torque depends on the engine, transmission ratios, weight, and other aspects of vehicle integration. A car with more torque will have a better driving feel, and usually better engineering and design. I use maximum torque divided by the listed RPM.[24] Together, torque, weight and price provide an objective, publicly observable measure of vehicle quality (Santini and Anderson 1993, EPA 2015, Gramlich 2010).

The last measure of quality is derived from the representative consumer discrete choice model in a differentiated product market, commonly used in industrial organization and in particular to model demand systems for automobiles. This measure is the unobserved quality in a price-only logit model.[25] Consider a consumer k with utility $U_{kit} = \alpha p_{it} + \xi_{it} + \epsilon_{kit}$. Here, p_{it} represents price for model i in market t, with coefficient $\alpha < 0$; and ξ_{it} represents

[23]Torque is the amount of force the engine can apply in a rotational manner, measured in nanometers. Horsepower is torque multiplied by a given speed (rotations-per-minute, or RPM), and determines the top speed of the vehicle.

[24]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. I also multiply by 100, because in native units RPM is about two orders of magnitude larger than torque.

[25]The Berry, Levinsohn and Pakes (1995) random coefficients approach, which yields more reasonable substitution patterns, is not needed here as I will not simulate counterfactual market shares. That approach adds considerable econometric complexity, with no benefit from the perspective of isolating ξ_j.

unobserved model quality. Suppose that ϵ_{kit} is i.i.d. across i and takes the type 1 extreme value distribution. Further, define $\delta_{it} = \alpha p_{it} + \xi_{it}$. Then the Berry (1994) inversion permits estimating δ_{it} as $\ln(\hat{s}_{it}) - \ln(\hat{s}_{0t}) = \alpha p_{it} + \xi_{it}$, where $\hat{s}_{it}$ is the market share for model i in market t, and $\hat{s}_{0t}$ is the outside good.[26] Normalizing the outside good to 0, and including market (year) fixed effects to soak up the outside good, I estimate $\ln(\hat{s}_{it}) = \alpha p_{it} + \tau_t + \xi_{it}$. The goal is to put as little structure on the data as possible, so I do not use nests or other observables.

Quality is clearly correlated with price. I follow Gandhi and Houde's (2016) suggestion for optimal instruments in differentiated product markets.[27] Specifically, Gandhi and Houde propose using functions of the differences between own and competitor product characteristics, based on the assumption that ξ_{it} and the overall market's menu of product characteristics $\mathbf{x}_t$ are independent. I employ the Gandhi-Houde differential instrument most appropriate for my setting. It is robust to variation in the number of products per market and uses characteristics of "close" rivals. Where $\mathbf{x}_t$ denotes a vector of characteristics ranging from 1 to L, and $\Delta_{it,i'}$ denotes the difference in characteristic x between model i and i', this instrument vector is:

$$A_i(\mathbf{x}_t) = \left\{ \sum_{i' \neq i} 1\left(\mid \Delta^1_{it,i'} \mid < \kappa^1\right) \mathbf{x}_{i't}, \ldots \sum_{i' \neq i} 1\left(\mid \Delta^L_{it,i'} \mid < \kappa^L\right) \mathbf{x}_{i't} \right\}. \tag{6}$$

The number of instruments is the same as the number of characteristics in $\mathbf{x}$. For each pair of models i and i', the difference in characteristics is only used if it is below threshold κ. Following Gandhi and Houde's suggestion, I set κ^l to be the standard deviation of the characteristic across all markets.

Two-stage least squares jointly estimates $\hat{p}_{it}$ with $A_i(\mathbf{x}_t)$ and $\ln(\hat{s}_{it}) = \alpha \hat{p}_{it} + \tau_t + \xi_{it}$.

[26] The error distribution implies that $\hat{s}_{it} = \frac{\exp(\delta_{it})}{1+\sum_{n=1}^{N}\exp(\delta_{nt})}$. Taking logs, we have $\ln(\hat{s}_{it}) = \delta_{it} - \log\left(1 + \sum_{n=1}^{N} \exp(\delta_{nt})\right)$. The equivalent expression for the outside good, $\ln(\hat{s}_{0t}) = 0 - \log\left(1 + \sum_{n=1}^{N} \exp(\delta_{nt})\right)$ is then subtracted to give the estimating equation.

[27] The conventional instruments - rival model characteristics - are well known to be weak in practice, as their optimal implementation grows so quickly in the number of products as to make computation prohibitive.

The measure of quality is the residual from the second stage, $\hat{\xi}_{it}$. I use $\hat{\xi}_{it}$ as a dependent variable and term it RCL quality (for "representative consumer logit"). Table 2 describes the procedure and the 2SLS results, using differential instruments in torque, price, and weight. In the first, stage, the multivariate F statistic demonstrates instrument relevance, and in the second stage, the LM and Wald F statistics strongly reject under-identification and weak identification, respectively. The resulting residual vector is summarized in Table 1.[28] One disadvantage with RCL quality is that it is measured with error, which potentially confounds the standard errors in the regression analysis. A second is that it suffers from the "black-box" structural assumptions of the logit model.

I restrict analysis to 3,177 models with sales of at least 1,000 units.[29] Of these, I have price for 3,128, torque for 2,726, weight for 2,643, and RCL quality for 2,697. Appendix Table 2 shows correlations among the variables. By construction, torque and horsepower are closely connected: after normalizing for RPM, their correlation is 0.96. Sales volume is negatively correlated with price and quality. 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 in Appendix Figure 4.

I use brands, such as Ford, Audi, BYD, and Roewe, as the primary unit of analysis. To avoid confusion, I term brands "firm," but the reader should be aware that some firms are 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 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. Figure 2 shows that Chinese

[28] I obtain very similar results for the the analysis with ξ_{it} in an exactly identified model using only the differential instrument in torque (not reported).

[29] I exclude models with low sales because they are typically intended only for the showroom or as token alternative fuel efforts.

brands proliferated over time, while their sales-weighted dollar prices decreased. Despite lower prices, Chinese firms are not dominant in the low end of the market.

JVs are not randomly assigned, making it difficult to disentangle the effects of state ownership and JV status. Figure 3 shows the number of active firms by type and year. My estimation relies on the small number of SOEs without JVs and private firms with JVs (six and three, respectively).[30] Appendix Table 3 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. There are likely many reasons that the composition of firms forming JVs is far from random. One reason may be a correlation of firm innovation capacity with the tendency to form a JV. While unobservable, such selection would be consistent with the paper's goal to evaluate the government's JV promotion. If only non-innovative firms select into JVs, the government should not be encouraging this behavior.

5 Empirical Strategy

Whether JVs cause domestic firms to innovate more or less depends on whether the negative effect of foreign partner profits outweighs the positive effect of lower technology acquisition cost. 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

[30] Unfortunately there are no consistent, reliable data on the share of a SOE that the government owns, so I cannot use this as a source of variation.

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.

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 final implementation in 2008-09 to tweak existing assembly processes to meet the standards and plan new models with the standards as a constraint.

There is a basic tradeoff between fuel economy, weight, and power. Knittel (2011) shows that among U.S. auto manufacturers, decreasing weight in passenger cars by 10% is associated with a 4.2% increase in fuel economy.[31] Automakers can meet new standards without new technology by building lighter, less powerful cars. Margins for adjustment that reduce quality include replacing parts with flimsier, lighter parts and downsizing the engine. Alternatively, automakers can maintain quality and meet the standards by acquiring fuel efficiency technologies, including discrete engine parts like catalytic converters and whole-vehicle design improvements in the power-train, aerodynamics and rolling resistance.[32] Heavier and more powerful vehicles generally have higher profit margins than other segments

[31] 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).

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

(IMF 2006).

To maintain existing models' quality, the fuel economy standards compelled domestic automakers to acquire fuel efficiency technologies and integrate them into the model design ($F_j(\phi_i) > 0$). Conversely, foreign firms - which had faced stringent fuel economy standards in Japan and Europe for decades - merely incurred the variable cost of inserting technologies developed for other markets into their China production ($F_{foreign} = 0$).

China 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.[33] 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 Table 1 lists the standards by weight class, and Appendix Figure 2 compares standards across countries).[34] 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.[35] 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).[36] 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

[33] See Wagner et al. (2009); Oliver et al. (2009); and An et al. (2007).

[34] 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.

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

[36] 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. 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. As of 2010, the vast majority of new models met the standards (see Appendix Figure 3).[37]

Estimating Equations

DD estimators pose two potential problems. First, the design fails if the policy is endogenous to the group studied. The fuel economy policy 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.[38]

I first estimate the following regression:

$$\begin{aligned} Y_{it} &= \alpha + \beta\left(\text{Policy}_t \cdot \text{Domestic}_j\right) + \gamma_1 \text{Policy}_t\left[+\gamma_2 \text{Domestic}_j\right] \\ &\quad \left[+\mathbf{1} \mid \text{Firm/Model/Class} = j/i/c\right] + \varepsilon_{ijt}. \end{aligned} \tag{7}$$

The coefficient of interest β is the effect of the policy on domestic firms relative to foreign firms.[39] Each observation is a model-year, where i denotes the model (such as the BYD F6 or the Chevrolet Spark), j the firm (such as Chery or Honda), and t the year. 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. In specifications that exclude firm fixed effects, I include Domestic_j, which is 1 if the firm is Chinese (such as BYD or Chery), and 0 if it is foreign (such as Nissan or GM).

[37] 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.

[38] See Bertrand, Duflo and Mullainathan (2004). I cluster standard errors in 78 groups (firms).

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

Policy_t is 1 if the year is 2009 or later, and 0 otherwise. In the primary specification, I use three years of data on either side of the policy and firm fixed effects. The fairly short time period raises the possibility that I observe a transition period, and some firms (i.e. those with JVs) may require longer to transition. However, domestic firms with JVs have underperformed for decades, suggesting that my findings reflect a problem with their technology acquisition capabilities, not simply a longer transition period.

The assumption that the error term is uncorrelated with the other variables is not directly testable, but I present evidence of pre-policy parallel trends and against selection into treatment in Section 7. Section 7 also contains a triple-difference specification exploiting the staged policy for new and continuing models, which addresses a number of the potential alternative stories.

I then interact the policy effect with JV and SOE status. A quadruple interaction estimates the effect of the policy on domestic firms that are SOEs with JVs, and triple interactions estimate the effect on private firms with JVs and SOEs without JVs.

$$\begin{aligned} Y_{it} &= \alpha + \beta_1 (\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j) + \beta_2 (\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV}_j) \\ &\quad + \beta_3 (\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{SOE}_j) + \beta_4 (\text{Policy}_t \cdot \text{Domestic}_j) \\ &\quad + \beta_5 (\text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j) + \gamma_1 \text{Policy}_t [+\gamma_2 \text{Has JV}_j] + \gamma_3 \text{SOE}_j \\ &\quad + [\mathbf{1} \mid \text{Firm/Class} = j/c] + \varepsilon_{ijt}. \end{aligned} \tag{8}$$

The coefficients of interest are β_1 through β_4, where β_4 gives the effect for private firms without JVs. I exclude the domestic individual effect because while no SOEs are foreign, all foreign firms have JVs. Thus with firm fixed effects $\gamma_2 \text{Has JV}_j$ is not identified. I also omit foreign firms to examine the effect of the policy when $\text{Domestic}_j = 1$. While this approach lacks the strength of the foreign firms as "control," it provides a clear test of the ARE.

The cannibalization channel predicts that the policy's negative effect should be strongest among domestic firms that compete most directly with their JV partner. I test the effect of pre-policy competition using variation in market segment and vehicle class. First, since there are effectively no Chinese models competing in the luxury market, I limit the sample to down-market segments. I estimate Equation 8 on models with below median price, torque, and weight. Second, I omit firms whose partners produce only high-end vehicles.[40]

Third, I proxy for competition by splitting the sample according to whether a domestic firm and its foreign partner both produced above median levels of a certain vehicle class prior to the policy. I examine the three minority classes: SUVs, minivans, and compacts.[41] I estimate Equation 7 on 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. The cannibalization effect should be larger for such pairs.

The alternative to the DD approach in Equations 7-8 is a detailed structural model, as in Berry, Levinsohn and Pakes (1995), Austin and Dinan (2005), and Allcott and Wozny (2014). Such a model could incorporate a lower fixed cost of improving fuel economy for firms with JVs, while estimated substitution patterns would predict more diversion from the foreign partner. Counterfactuals without the cannibalization channel could be estimated. However, such models assume profit maximization and Bertrand competition, which are not appropriate in the Chinese context. The natural experiment approach that I take, combined with the representative consumer logit-derived quality measure, is better suited to analyzing incentives for technology upgrading in a mixed economy.

[40] Specifically, I exclude partners of BMW and Mercedes-Benz (Beiqi, Beiqi Weiwang, Zhanqi, Brilliance).

[41] An alternative is to normalize the sales in a class by a firm's overall sales. I find somewhat similar results (not shown) using such a metric. However, note that in the first order condition (Equation 4), profit cannibalization depends on the change in foreign firm profits with respect to a quality change in the domestic firm's model. This in large part depends on the number of vehicles in that class (e.g. SUVs) that the foreign firm sells. The firm's fraction of sales that are SUVs is therefore a less direct measure of competition.

6 Results

Descriptive Results

Domestic firms - particularly those with JVs - responded to the 2009 fuel economy standard by manufacturing less powerful, cheaper, and lighter vehicles. Figures 5-11 are scatterplots of annual model averages by firm type. The data are too noisy at this level of aggregation to include confidence intervals. Figure 5 shows that domestic firms reduced prices in 2009, while foreign prices were unchanged (note the different axes). Figures 6-8 show log torque, log price, and representative consumer logit (RCL) quality in the three-year window around the policy. These figures provide evidence for continuity around the policy among foreign firms, though Figure 8 suggests a discontinuity; see Section 7 for pre-trend tests. Among domestic firms, all three metrics fall in 2009, the year of the policy. Torque recovers somewhat, but the other two do not.

Figures 9-11 consider only domestic firms, and split the firms by JV and SOE status. Firms with JVs seem responsible for the fall around the policy; this is particularly striking for RCL quality. Private firms had a decreasing trend pre-policy, consistent with aiming to capture lower-end market share.[42]

Empirically, exporting is strongly associated with firm productivity and competitiveness.[43] Chinese government policy explicitly encourages auto exports (State Council 2009). Total exports were only 0.6 million vehicles in 2012. Since 2008, private firms and local SOEs without JVs have been responsible for almost all passenger vehicle exports, depicted in Figure 4.[44] Though increasing, they remain far from meeting government targets (Roland Berger 2013).

[42] Similar graphs for weight, not reported for brevity, provide generally similar visual results.

[43] See Clerides, Lach and Tybout (1998); Melitz and Redding (2012); and Giles and Williams (2000).

[44] 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.

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).

Regression Results

Estimates of Equation 7, using a three year window on either side of the policy, are in Table 3. The standards reduced torque in domestic models relative to foreign models by 11%. They reduced price by 15%, weight by 65 kg (about 5% of the mean), and RCL quality by about 60% of its mean. All are significant at the 1% or 5% levels.[45] With model fixed effects, the policy's effect on torque declines but remains significant (Panel 1 V). With firm and class (SUV, minivan, sedan) fixed effects, the results are similar to the main specification (Panel 1 VI-VII). Controlling for sales volume, in Panel 2 I-III, also yields similar results. While the policy may affect model sales volume, including it obviates concern that results stem from differential vehicle mix shifting across firm types. The effects become larger and more significant when I expand the bandwidth to all years (1999-2013), in Panel 2 IV-VI. This indicates that domestic firms did not catch up to foreign firms in 2012 and 2013, despite the increasing trend from Figure 6.

I split the sample by domestic firm type in Table 4. The policy's effect strengthens when the domestic firm sample is limited to those with JVs (I), at -16% for torque, -23% for price, and -100 kg for weight. These are significant at the 1% level. Among SOEs and SOEs without JVs (II-III), the effects are smaller, but mostly still significantly negative and slightly higher than the full sample effects in Table 3. The exception is RCL quality, where

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

the effect is slightly higher for SOEs without JVs. Among private firms with and without JVs (IV-V), the coefficients are insignificant for all characteristics, and they are near zero for private firms without JVs.

To establish whether these coefficients are significantly different from one another, I estimate Equation 8 in Table 5. The policy-domestic interaction is modulated with JV and SOE status. The coefficients are relative to foreign firms, and the dummy for being private in the interaction with domestic firm types is omitted. I report the three-way interactions and the quadruple interaction. This estimation, shown in Panel 1, confirms that domestic firms with JVs - rather than simply SOEs - are responsible for the negative effect. The effects are large in magnitude and statistically significant. Panel 2 limits the sample to domestic firms, comparing responses to the policy across domestic firm types. The policy reduced torque by 18% and price by 16% among JVs, controlling for the policy's effect on SOEs and the four individual effects. Weight and RCL quality lose significance.

Next, I show that the policy had stronger effects on firms that competed more intensively with their foreign partners ex-ante. Table 6 I-III limit the sample to the bottom half of the market, considering only models with below-median price, torque, and weight, respectively.[46] The effects increase to -23% for torque and price, and -71 kg for weight. IV-VII omit domestic firms with high-end partners. The effects on all four characteristics are again stronger than in the main specification, and the effects on weight and RCL quality increase dramatically.

Table 7 contains the class distribution proxy for competition. Panel 1 includes only the subset of JVs where both partners produced above-median levels of SUVs in the three years before the policy. The policy effect is -31% for torque, -17% for price, -150 kg for weight, and -.55 for RCL quality, significant at the 1%, 10%, 5%, and 5% levels respectively. These are all much larger than in the primary full-sample specification in Table 3, except for RCL quality, which is roughly the same. Panels 2 and 3 I examine partners that specialized

[46] The below-median approach to market segmentation does not apply to the RCL quality measure, since $A_i(\mathbf{x}_t)$ is constructed relative to other models in the market.

in minivans and compacts, respectively, before the policy. They yield somewhat stronger effects on torque and RCL quality than the full-sample specification. The fuel economy policy was weight-based and thus had different effects on different classes, in particular favoring smaller cars. Such differential overall policy effects should, in the absence of a cannibalization channel, result in the policy having inconsistent effects across classes. That is, the stronger negative effect of the policy on quality among domestic firms producing SUVs should be counteracted by a comparably weaker effect on domestic producers of compact cars. In contrast, I find that the stronger negative effect of the policy on quality persists in all three panels.

In general, the 95% confidence intervals for the coefficients in Tables 6 and 7 include the full sample results in Table 5 Panel 1. The precise specifications used do not permit testing whether the coefficients are equal, but in many of the cases I can use slightly different specifications and confidently reject that the coefficients are equal in a χ^2 test.[47]

Thus when partners produced nearer-substitutes pre-policy, the fuel economy standards caused a more extreme reduction in quality and price. 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 when the partner firm produces in similar segments.[48] The cannibalization channel appears to outweigh any benefits from knowledge spillovers in the JV. Industrial policy often focuses on increasing or decreasing competition. Perversely, in a JV where the cannibalization channel dominates, more competition with the foreign partner has a negative impact on technology upgrading.

[47] For example, I can reject that the coefficients on $\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV}_j$ for RCL quality across Table 5 Panel 1 IV and Table 6 VIII are the same with 90% confidence.

[48] 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.

7 Robustness

A central concern, particularly since JVs are not randomly assigned, is whether a systematic difference across firms unrelated to their JV status led to different reactions to the policy. This section establishes parallel trends, provides a more stringent alternative specification of the main result exploiting the staged policy implementation, and describes a variety of standard robustness tests.

Pre-Policy Trends and Year-Specific Effects

It is critical to demonstrate no pre-existing trends at the time of the policy in 2009. If model characteristics across types were on similar growth paths before the policy, the effects that I observe are more readily interpretable as reactions to the policy. Although the Chinese auto industry grew and changed dramatically between 2006 and 2012, the specification is valid if market shocks affected both foreign and domestic firms. I test for statistically different trends over time in model characteristics before the policy using the following regression, in which i indexes models, j firms, and t years, are of the form

$$Y_{it} = \alpha + \beta\,(\text{Year}_t \cdot X_j) + \gamma_1 \text{Year}_t + [\mathbf{1} \mid \text{Firm} = j] + \varepsilon_{ijt}. \tag{9}$$

In Appendix Table 4 Panels 1, 2, and 3, X_j = Domestic$_j$, Has JV$_j$, and SOE$_j$, respectively. Year$_t$ is a continuous variable from 1999 to 2008. All three panels demonstrate no statistically significant difference in trends across firm types prior to the policy ($\hat{\beta}$ coefficients are all near zero and insignificant). The time trend is mostly positive and slightly significant, reflecting some secular quality improvement before the policy.

In a second specification, I include year fixed effects and interactions around the policy. Equation 10 estimates the effect of each year, for three years prior to the policy and all years since.

$$Y_{it} = \alpha + \sum_{t=2006}^{2013} (\beta_t \text{Year}_t \cdot X_j + \gamma_t \text{Year}_t) + [\mathbf{1} \mid \text{Firm} = j] + \varepsilon_{ijt}. \tag{10}$$

While there is inadequate power to obtain negative and significant coefficients on all post-policy years, the regression results in Appendix Table 5 show (a) parallel pre-trends; and (b) year-specific evidence of the post-policy treatment effect. Although the financial crisis of 2008 did not have a large effect on the Chinese market, the subsequent global recession certainly affected foreign firms in China. The results may reflect foreign pricing pressures as they faced changes in their outside options. Figures 5-8, as well as the regression analysis in this section, indicate that foreign firms continued on their prior path after the policy.

Triple-Differences

I confirm the main finding of the negative policy effect on domestic firms in a triple-differences design that exploits the standards' staged implementation. The standard applied only to new models in 2008, but to both new and continuing models in 2009. 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. Automakers sensitive to the policy may have changed new model but not continuing model characteristics in 2008. The estimating equation is:

$$\begin{aligned} Y_{it} &= \alpha + \beta \left(\text{Policy}_t^{2008} \cdot \text{Domestic}_j \cdot \text{Continuing}_{it}\right) + \gamma_1 \left(\text{Policy}_t^{2008} \cdot \text{Domestic}_j\right) \\ &\quad + \gamma_2 \left(\text{Policy}_t^{2008} \cdot \text{Continuing}_{it}\right) + \gamma_3 \left(\text{Continuing}_{it} \cdot \text{Domestic}_j\right) \\ &\quad + \gamma_4 \text{Policy}_t + \gamma_6 \text{Continuing}_{it} + (\mathbf{1} \mid \text{Firm} = j) + \varepsilon_{ijt}. \end{aligned} \tag{11}$$

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 8 shows that in 2008, domestic firms' continuing models were more powerful, more expensive, heavier, and had higher unobserved quality than new models already subject to the policy, relative to the same comparison within foreign firms. 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.[49] Note that the coefficients on the individual indicators and interactions are not direct effects.[50]

Additional robustness tests

As firms can form new JVs, there may be concern about selection into treatment. Domestic firms may have anticipated the high costs of meeting the standards while maintaining quality, and opted into JVs as a result. This behavior would undermine the empirical design. However, such expectations are at odds with the fact that domestic firms with JVs reduced quality and price in response to the standards. Regardless, Figure 3 shows little entry and exit into and out of categories in the three years around the 2009 policy. Only two JVs formed after the standards were announced but before implementation.[51] There was also no sudden increase in JVs after the standards. Based on Figure 3 and anecdotal evidence from the press, JVs were not perceived by domestic firms as a means to deal with the standards, consistent with my conclusion that JVs have not been an efficient technology transfer mechanism.

Next, I conduct key robustness tests of the main result for torque. Table 9 Panel 1 I-II show the Policy_t and Domestic_j interaction and individual effects. The coefficient on the interaction is -7%, significant at the 10% level, without the individual effects. Panel 1 III omits fixed effects, instead including the Domestic_j individual effect. Panel 1 IV includes both year and firm fixed effects. Year fixed effects should alleviate concerns that the global recession coincided with the policy. 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). Panel 1 V replaces the sales volume requirement of 1,000 units with 5,000 units. The main finding is intact in all these specifications.

[49] 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.

[50] 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.

[51] These are Chang'an-Mazda and SouEast-Mitsubishi, both announced in 2006.

Panel 2 I-III of Table 9 shows that the result is robust to alternative assumptions about standard errors: brand-year, robust (no clusters), and two-way clustering (Cameron-Gelbach-Miller). Placebo tests in which the policy is artificially set to 2006 and 2005 are in Panel 2 columns IV-V. The coefficient is near-zero for 2006. For 2007 it is -.077, significant at the 10%, which is not surprising as this includes the first part of the policy. In unreported estimation, I do not find a strong difference between central and local SOEs in their policy response. I do not find effects on length or height. They are less relevant to the quality-fuel economy tradeoff.

8 Conclusion

Understanding the conditions in which firms acquire new technologies is vital to explaining income disparities across countries, and more specifically to evaluating infant industry protection (Parente and Prescott 1994). I present evidence that the JV mandate in China's auto sector is a distortionary barrier to technology adoption. Ending it, however, might be politically challenging because of opposition from incumbents, as in Caselli and Gennaioli (2008). I find that private firms, permitted to enter fairly recently, upgraded technology the most in response to the fuel economy standards, consistent with financial reforms in the Caselli-Gennaioli framework being an easier institutional path.

Conventional trade models like 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 and Prescott (2015) 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 than to 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.

China's JV mandate, substantial state ownership, and high import tariffs contrast with the Japanese, Taiwanese, and South Korean experiences. Auto sector development in those countries featured an absence of FDI and little direct cooperation with foreign firms, but intensive licensing of foreign technology and reverse engineering.[52] 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.

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. Yet there is evidence that the 2009 situation remains the status quo. 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).

[52] See Goto and Odagiri (2003); Kim (2003); and Aw (2003).

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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)	RCL quality
				Panel 1: All Firms						
Mean	136,089	31,209	122,340	16,834	170	4.33	1,332	1,546	4,422	.75
Median	103,900	13,882	109,169	14,870	156	3.80	1,304	1,483	4,500	.76
Std dev	103,755	55,186	81,684	11,694	59.7	2.19	298	156	416	1.38
N	3,128	3,177	3,194	3,087	2,726	2,715	2,643	2,723	2,724	2,697
				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	1.04
Median	131,800	11,867	133,618	17,655	170	4.00	1,304	1,472	4,520	1.02
Std dev	112,308	33,417	85,141	11,400	57.6	2.26	283	107	395	1.25
N	437	438	438	436	405	405	405	410	410	405
				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	1.36
Median	134,800	17,302	137,528	18,510	177.5	4.08	1,386	1,484	4,540	1.46
Std dev	114,900	43,482	78,291	12,097	62.4	2.69	282	101	363	1.33
N	639	644	644	642	610	610	598	610	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	.48
Median	74,300	7,508	77,669	8,385	143	3.42	1,200	1,521	4,434	.23
Std dev	46,675	56,317	40,805	5,837	48.7	2.19	322	186	482	1.35
N	280	290	287	253	233	231	221	225	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	.31
Median	66,350	13,289	64,932	9,593	136	3.20	1,200	1,495	4,375	.33
Std dev	32,085	96,082	27,022	4,425	41.4	1.77	267	225	438	1.41
N	436	448	446	426	398	397	375	385	386	387

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: Representative Consumer Logit 2SLS Estimation Results

	First stage: Dependent variable is price	*Second stage: Dependent variable is* $\ln(\hat{s}_{it})$
	I.	II.
Δ^{Torque}	-33.4***	
	(1.63)	
Δ^{Price}	-.095***	
	(.0027)	
Δ^{Weight}	-.56***	
	(.11)	
$\hat{p}_{it}$		-3.2e-6***
		3.6e-7
Year effects	Y	Y
N	3255	3255
R^2		0.14
Sanderson-Windmeijer multivariate F test p-value	0.00***	
Kleibergen-Paap rk LM statistic χ^2 p-value		0.00***
Kleibergen-Paap rk Wald F statistic		2414

Note: This table reports estimates from a two-stage-least-squares (2SLS) estimation of the price coefficient in a standard multinomial logit model of a representative consumer in a differentiated products market. The estimating equation is $\ln(\hat{s}_{it}) = \alpha\hat{p}_{it} + \tau_t + \xi_{it}$, where $\hat{p}_{it}$ is estimated in the first stage using $A_i(\mathbf{x}_t)$, as described in Section 5, and $\hat{s}_{it}$ denotes market share for model i in market t. Includes all years of data as markets, so the sample size is much larger than in subsequent analysis. Standard errors are robust . *** indicates $p < .01$.

Table 3: Fuel Economy Policy Impact on Domestic Firms

Panel 1: Baseline specification & Alternate fixed effects

Dependent variable:	Log torque	Log price	Weight	RCL quality	Log torque		
					Model f.e.	Firm & class f.e.	Class f.e.
	I.	II.	III.	IV.	V.	VI.	VII.
$\text{Policy}_t \cdot \text{Domestic}_j$	-.11**	-.15***	-65**	-.62***	-.065**	-.095**	-.11*
	(.046)	(.046)	(29)	(.12)	(.026)	(.046)	(.055)
Policy_t	.037*	.034	31**	.34***	.025	.035	.04*
	(.022)	(.022)	(13)	(.078)	(.018)	(.021)	(.023)
Domestic_j							-.18**
							(.086)
Firm f.e.	Y	Y	Y	Y	N	Y	N
Model f.e.	N	N	N	N	Y	N	N
Class f.e.	N	N	N	N	N	Y	Y
N	1643	1653	1599	1627	1643	1643	1643
R^2	0.06	0.2	0.07	0.091	0.900	0.11	0.142

Panel 2: Conditional on sales and all years

				All years (2002-2013)			
Dependent variable:	Log torque	Log price	Weight	Log torque	Log price	Weight	RCL Quality
	I.	II.	III.	IV.	V.	VI.	VII.
$\text{Policy}_t \cdot \text{Domestic}_j$	-.1**	-.15***	-60**	-.13**	-.22***	-90**	-.69***
	(.047)	(.048)	(29)	(.055)	(.067)	(39)	(.096)
Policy_t	.045**	.047**	37***	.11***	-.013	80***	.44***
	(.022)	(.022)	(13)	(.024)	(.027)	(17)	(.062)
Sales Volume_i	-9.6e-07***	-1.5e-06***	-.00069***				
	(3.2e-07)	(4.3e-07)	(.00024)				
Firm f.e.	Y	Y	Y	Y	Y	Y	Y
N	1643	1653	1599	2032	2062	1986	2020
R^2	0.07	0.13	0.04	0.076	0.21	0.048	0.13

Note: This table reports difference-in-differences regression estimates of the effect of the 2009 fuel economy standards on domestic firms. Observations it are new model-years. Estimates are variants of:

$$Y_{it} = \alpha + \beta\,(\text{Policy}_t \cdot \text{Domestic}_j) + \gamma_1 \text{Policy}_t\,[+\gamma_2 \text{Domestic}_j] \\ [+\mathbf{1} \mid \text{Firm/Model/Class} = j/i/c] + \varepsilon_{ijt}.$$

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 (Firm Type Splits)

Panel 1: Dependent variable = Log torque					
Sample:	Firms w/ JVs	SOEs	SOEs w/o JVs	Private	Private w/o JVs
	I.	II.	III.	IV.	V.
$Policy_t \cdot Domestic_j$	-.16***	-.12***	-.13**	-.1	-.058
	(.061)	(.047)	(.051)	(.078)	(.093)
$Policy_t$	.038*	.037*	.037*	.039*	.039*
	(.022)	(.022)	(.022)	(.022)	(.022)
N	1293	1377	1154	1281	1226
R^2	0.09	0.07	0.04	0.12	0.06
Panel 2: Dependent variable = Log price					
Sample:	Firms w/ JVs	SOEs	SOEs w/o JVs	Private	Private w/o JVs
	I.	II.	III.	IV.	V.
$Policy_t \cdot Domestic_j$	-.23***	-.21***	-.19**	-.1	-.062
	(.066)	(.057)	(.076)	(.067)	(.074)
$Policy_t$	.03	.031	.023	.029	.029
	(.022)	(.022)	(.022)	(.022)	(.022)
N	1303	1388	1166	1294	1242
R^2	0.31	0.31	0.26	0.44	0.43
Panel 3: Dependent Variable = Weight (kg)					
Sample:	Firms w/ JVs	SOEs	SOEs w/o JVs	Private	Private w/o JVs
	I.	II.	III.	IV.	V.
$Policy_t \cdot Domestic_j$	-100***	-74***	-61	-63	-41
	(26)	(26)	(49)	(52)	(62)
$Policy_t$	32**	32**	31**	31**	32**
	(13)	(13)	(13)	(13)	(13)
Firm f.e.	Y	Y	Y	Y	Y
N	1263	1345	1135	1257	1207
R^2	0.07	0.05	0.01	0.1	0.06
Panel 4: Dependent Variable = RCL Quality					
Sample:	Firms w/ JVs	SOEs	SOEs w/o JVs	Private	Private w/o JVs
	I.	II.	III.	IV.	V.
$Policy_t \cdot Domestic_j$	-.78***	-.86***	-.89***	-.3	-.14
	(.16)	(.16)	(.17)	(.19)	(.19)
$Policy_t$	.32***	.31***	.31***	.33***	.32***
	(.11)	(.11)	(.11)	(.1)	(.11)
N	1283	1366	1150	1276	1224
R^2	0.095	0.079	0.031	0.042	0.023
Firm f.e.	Y	Y	Y	Y	Y

Note: This table reports difference-in-differences regression estimates of the effect of the 2009 fuel economy standards on domestic firms. Each model includes only domestic firms of the type specified, and all foreign firms. Observations *it* are new model-years. Estimates are variants of Equation 7; all include firm f.e.. 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: All firms (effect measured relative to foreign firms)

Dependent variable:	Log torque	Log price	Weight	RCL Quality
	I.	II.	III.	IV.
$\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV}_j$	-.16*	-.2***	-111*	-.75***
	(.083)	(.052)	(65)	(.25)
$\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{SOE}_j$	-.045	-.019	-24	-.27
	(.063)	(.056)	(41)	(.25)
$\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV}_j \cdot \text{SOE}_j$	.12	.12	102	.4*
	(.095)	(.088)	(66)	(.24)
$\text{Domestic}_j \cdot \text{Has JV}_j \cdot \text{SOE}_j$	-.14	-.26	-259**	.16
	(.23)	(.22)	(124)	(.58)
Domestic-Policy & individual effects	Y	Y	Y	Y
Firm & class f.e.	Y	Y	Y	Y
N	1643	1653	1599	1627
R^2	0.34	0.42	0.28	0.122

Panel 2: Domestic firms (effect measured relative to other domestic firms)

Dependent variable:	Log torque	Log price	Weight	RCL Quality
	I.	II.	III.	IV.
$\text{Policy}_t \cdot \text{Has JV}_j$	-.18*	-.16***	-114	-.26
	(.097)	(.058)	(85)	(.29)
$\text{Policy}_t \cdot \text{SOE}_j$	-.11	-.054	-87	.84**
	(.17)	(.16)	(120)	(.42)
$\text{Policy}_t \cdot \text{Has JV}_j \cdot \text{SOE}_j$	.14	.071	104	-.085
	(.11)	(.084)	(82)	(.23)
$\text{Has JV}_j \cdot \text{SOE}_j$	-.11	.095	-111	1.1*
	(.2)	(.17)	(109)	(.65)
Individual effects	Y	Y	Y	Y
Firm & class f.e.	Y	Y	Y	Y
N	628	624	596	612
R^2	0.23	0.04	0.22	0.02

Note: This table reports regression estimates of the effect of the 2009 fuel economy standards on domestic firms at the model-year level, using variants of Equation 8. Panel 2 omits foreign firms and thus all non-identified terms from Equation 8. Policy_t is 1 if the year is 2009-11, and 0 if 2006-08. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 6: Fuel Economy Policy Impact on Domestic Firms with Market Segmentation (Firm Type Interactions)

Market segment:	Models with above-median dependent variable values omitted			Firms with luxury foreign partners omitted†			
Dependent variable:	Log torque	Log price	Weight	Log torque	Log price	Weight	RCL Quality
	I.	II.	III.	IV.	V.	VI.	VII.
$\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV}_j$	-.23***	-.23*	-71**	-.22*	-.25***	-196*	-1.1***
	(.047)	(.12)	(35)	(.12)	(.068)	(102)	(.33)
$\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{SOE}_j$	.03	.033	18*	.022	.0045	20	-.46
	(.021)	(.024)	(10)	(.021)	(.024)	(15)	(.49)
$\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV}_j \cdot \text{SOE}_j$	.13**	.18	17	.19	.17*	196*	.73**
	(.058)	(.13)	(28)	(.13)	(.095)	(105)	(.35)
$\text{Domestic}_j \cdot \text{Has JV}_j \cdot \text{SOE}_j$	-.11	-.11	-2.5	-.24	-.24	-319**	-.059
	(.078)	(.14)	(53)	(.24)	(.24)	(154)	(.62)
Domestic-Policy & individual effects	Y	Y	Y	Y	Y	Y	Y
Firm & class f.e.	Y	Y	Y	Y	Y	Y	Y
N	866	850	810	1605	1614	1562	1588
R^2	0.34	0.58	0.22	0.16	0.36	0.25	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 Equation 8:

$$\begin{aligned} Y_{it} \;=\; & \alpha + \beta_1 \left(\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j\right) + \beta_2 \left(\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV}_j\right) + \beta_3 \left(\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{SOE}_j\right) \\ & + \beta_4 \left(\text{Policy}_t \cdot \text{Domestic}_j\right) + \beta_5 \left(\text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j\right) \\ & + \gamma_1 \text{Policy}_t \left[+\gamma_2 \text{Has JV}_j\right] + \gamma_3 \text{SOE}_j + \left[\mathbf{1} \mid \text{Firm/Class} = j/c\right] + \varepsilon_{ijt}. \end{aligned}$$

Policy_t is 1 if the year is 2009-11, and 0 if 2006-08. Standard errors are robust and clustered by firm. †Domestic firms that have JVs with BMW or Mercedes-Benz omitted. *** indicates $p < .01$.

Table 7: Fuel Economy Policy Impact on Domestic Firms (Pre-Policy Competition)

Panel 1: Sample limited to JVs in which both partners produced above-median SUVs before policy

Dependent variable:	Log torque	Log price	Weight	RCL Quality
	I.	II.	III.	IV.
$\text{Policy}_t \cdot \text{Domestic}_j$	-.31***	-.17*	-149**	-.55**
	(.1)	(.093)	(71)	(.25)
Policy_t	.12*	.042	32	.48***
	(.07)	(.066)	(39)	(.15)
Domestic_j	.043	-.7***	-1.9	-1***
	(.14)	(.11)	(91)	(.36)
N	895	984	876	889
R^2	.052	.42	.043	.19

Panel 2: Sample limited to JVs in which both partners produced above-median minivans before policy

Dependent variable:	Log torque	Log price	Weight	RCL Quality
	I.	II.	III.	IV.
$\text{Policy}_t \cdot \text{Domestic}_j$	-.16***	-.16***	-91***	-.9***
	(.048)	(.059)	(35)	(.27)
Policy_t	.051**	.0039	26*	.52***
	(.022)	(.027)	(15)	(.18)
Domestic_j	-.2*	-.84***	-123	-.33
	(.12)	(.19)	(105)	(.3)
N	866	936	846	860
R^2	0.11	0.35	0.034	0.11

Panel 3: Sample limited to JVs in which both partners produced above-median compact cars before policy

Dependent variable:	Log torque	Log price	Weight	RCL Quality
	I.	II.	III.	IV.
$\text{Policy}_t \cdot \text{Domestic}_j$	-.14***	-.14**	-60*	-.74***
	(.046)	(.066)	(31)	(.28)
Policy_t	.098***	.06	49**	.52***
	(.028)	(.037)	(19)	(.19)
Domestic_j	-.18	-.5***	-28	-.22
	(.11)	(.15)	(74)	(.23)
N	708	746	688	704
R^2	0.15	0.28	0.022	0.074

Note: This table reports estimates of the effect of the 2009 fuel economy standards on domestic firms, using variants of: $Y_{it} = \alpha + \beta\,(\text{Policy}_t \cdot \text{Domestic}_j) + \gamma_1 \text{Policy}_t + \gamma_2 \text{Domestic}_j + \varepsilon_{ijt}$. The sample excludes domestic firms without a JV and further limits the sample to JV partnerships where the domestic and foreign firms both produced above-median levels of a certain class of vehicle prior to the policy (SUVs, minivans, or compacts). Policy_t is 1 if the year is 2009-11, and 0 if 2006-08. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 8: Fuel Economy Policy Impact on Domestic Firms (Triple-Differences)

	With firm f.e.				Without firm f.e.			
Dependent variable:	Log torque	Log price	Weight	RCL Quality	Log torque	Log price	Weight	RCL Quality
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
$\text{Policy}_t^{2008} \cdot \text{Domestic}_j \cdot \text{Continuing}_i$	.068*	.24***	129*	.47**	.19**	.22*	143**	.32*
	(.018)	(.021)	(31)	(.081)	(.02)	(.066)	(21)	(.092)
$\text{Policy}_t^{2008} \cdot \text{Domestic}_j$	-.086*	-.18***	-126*	-.29***	-.2***	-.19*	-137**	-.2**
	(.023)	(.017)	(34)	(.024)	(.015)	(.057)	(26)	(.043)
$\text{Domestic}_j \cdot \text{Continuing}_i$	.067	-.094*	-54	-.16	-.02	-.012	-65*	-.12
	(.024)	(.022)	(33)	(.12)	(.02)	(.066)	(21)	(.089)
$\text{Policy}_t^{2008} \cdot \text{Continuing}_i$	-.00015	-.055	-.72	-.15	.015	.029***	25	-.16
	(.02)	(.028)	(9.3)	(.1)	(.012)	(.0015)	(34)	(.15)
Policy_t^{2008}	.012	.034	5.8	-.0076	.018*	.0086	-11	.053
	(.0086)	(.021)	(13)	(.043)	(.0053)	(.008)	(36)	(.088)
Domestic_j					-.13**	-.67***	-3.3	-.47***
					(.014)	(.057)	(26)	(.041)
Continuing_i	-.072	.026	32*	.28	-.064**	-.046***	-2	.43
	(.027)	(.022)	(8.1)	(.11)	(.0093)	(.003)	(35)	(.16)
Firm f.e.	Y	Y	Y	Y	N	N	N	N
N	636	646	626	630	636	646	626	630
R^2	0.579	0.692	0.562	.74	.08	.29	.047	.52

Note: This table reports difference-in-differences regression estimates of the effect of the 2009 fuel economy standards on domestic firms. Observations it are new model-years. 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 included as a control (the number of units sold). Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 9: Key Robustness Tests

Dependent variable: Log Torque

Panel 1

	Individual effects		Fixed effects		Sales vol≥ 5,000 units
	I.	II.	III.	IV.	V.
$\text{Policy}_t \cdot \text{Domestic}_j$	-.07*		-.13**	-.091*	-.13***
	(.042)		(.058)	(.051)	(.042)
Policy_t		-.00017	.045*	.057*	.062***
		(.023)	(.024)	(.031)	(.02)
Domestic_j			-.15		
			(.094)		
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	0.03	0.071	0.495	0.07

Panel 2

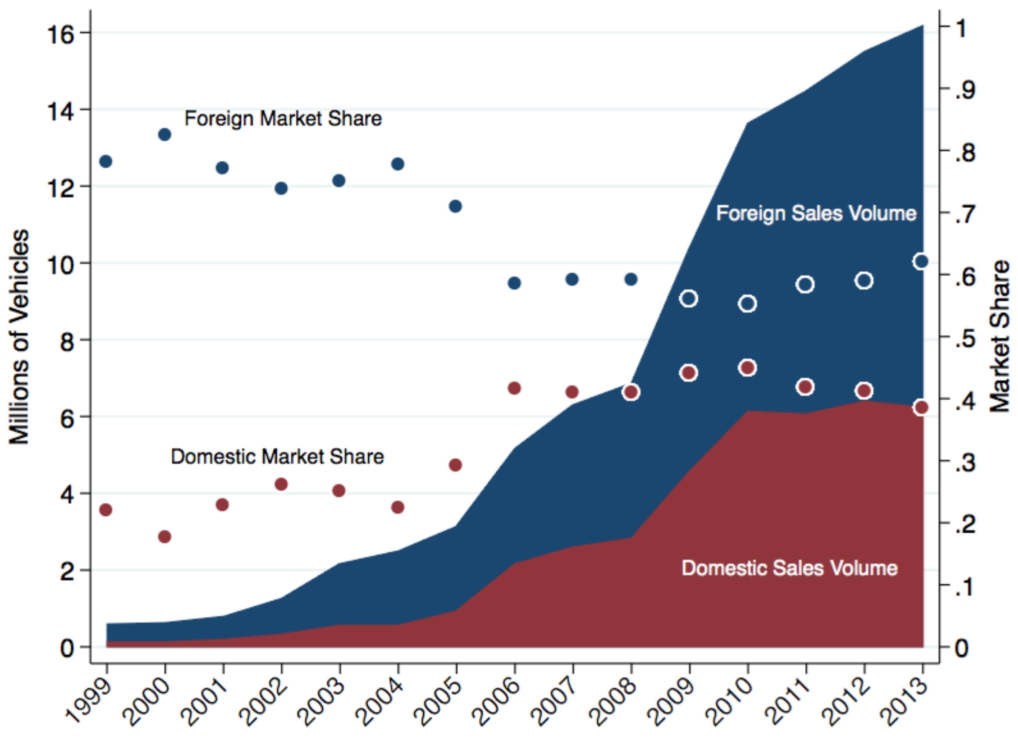
	Standard error clustering			Placebo test with artificial policy in year:	
	Brand-year	Robust	Two-way firm yr (Cam.-Gelbach-Miller)	2006	2007
	I.	II.	III.	IV.	V.
$\text{Policy}_t \cdot \text{Domestic}_j$	-.092***	-.11**	-.092**	-.0068	-.077*
	(.028)	(.046)	(.042)	(.049)	(.04)
Policy_t	.033**	.037*	.033*	.036	.038*
	(.015)	(.022)	(.018)	(.03)	(.021)
Firm f.e.	Y	Y	Y	Y	Y
N	1643	1643	824	1051	1643
R^2	0.495	0.07	0.09	0.07	0.495

Note: This table reports difference-in-differences regression estimates of the effect of the 2009 fuel economy standards on the torque of domestic firm models. Observations it are new model-years. Estimates are variants of:

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

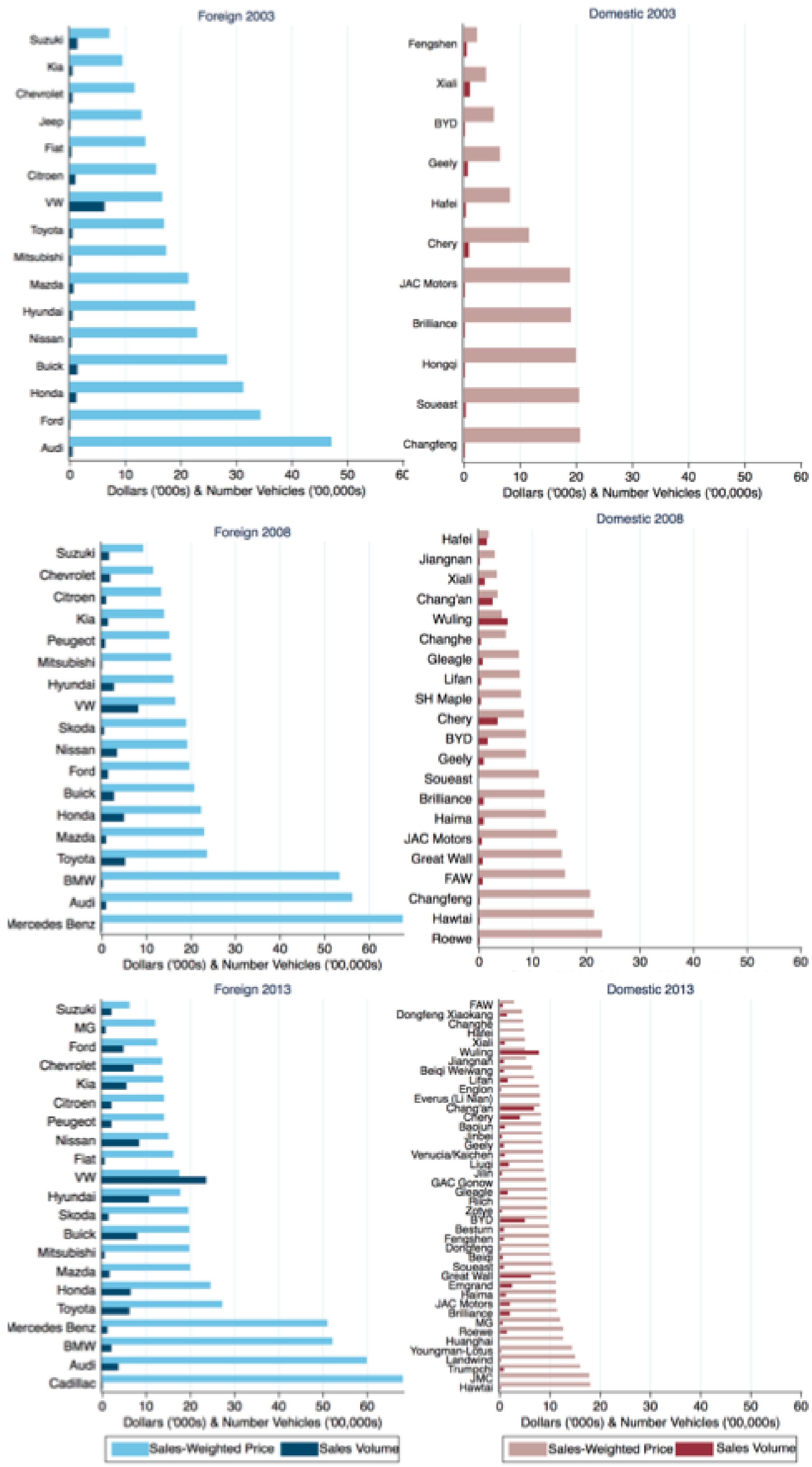
Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. Policy_t is 1 if the year is 2009-11, and 0 if 2006-08. Sales volume is the number of units sold. Standard errors are robust and clustered by firm, except where specified. *** indicates $p < .01$.

Figure 1: Sales Volume and Market Share by Firm Type



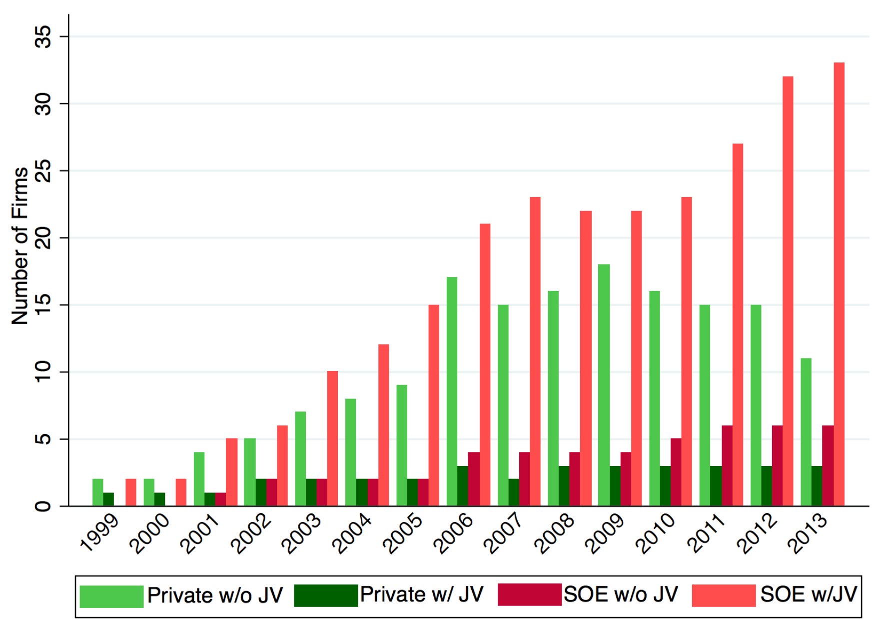
Note: This figure shows foreign and domestic brand Chinese sales volume (number of new vehicles sold in a given year) on the left axis, where the blue area is foreign and the red area is domestic. Market share of sales volume is on the right axis and in the foreign (blue) and domestic (red) scatterplot.

Figure 2: Sales Volume and Sales-Weighted Price by Firm



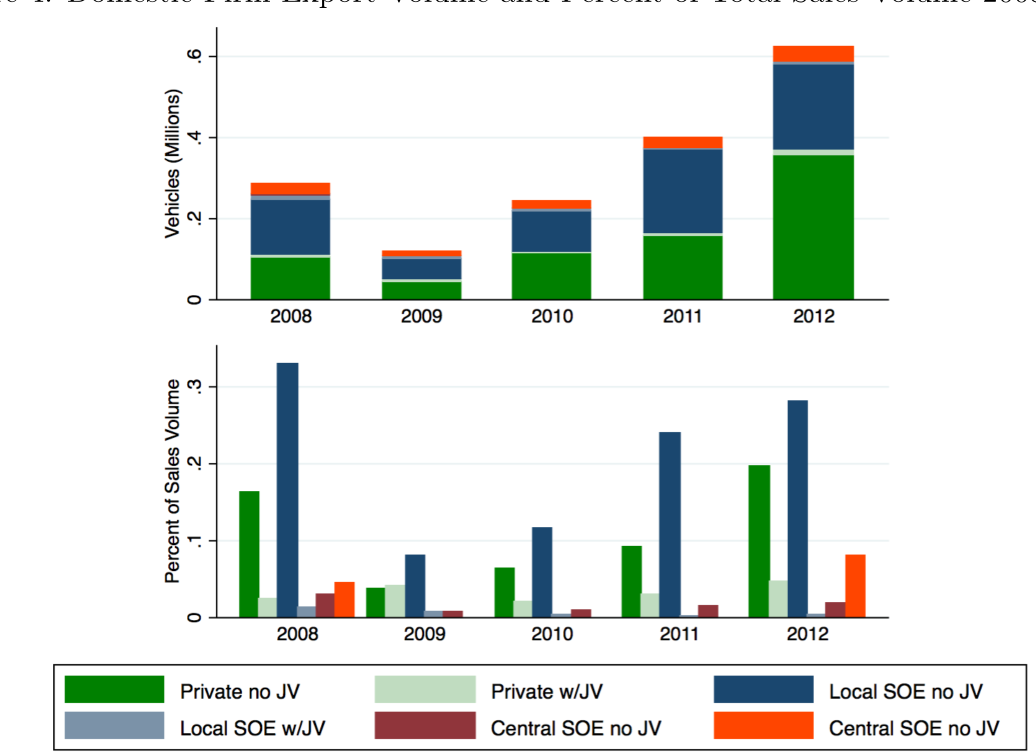
Note: This figure shows firm sales volume (number of vehicles) and sales-weighted average price across models sold.

Figure 3: Number of Active Firms by Type



Note: This figure shows the number of domestic (Chinese) firms with positive sales in each of four categories: Privately-owned with and without a joint venture, privately owned with a joint venture, and state-owned with and without a joint venture.

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

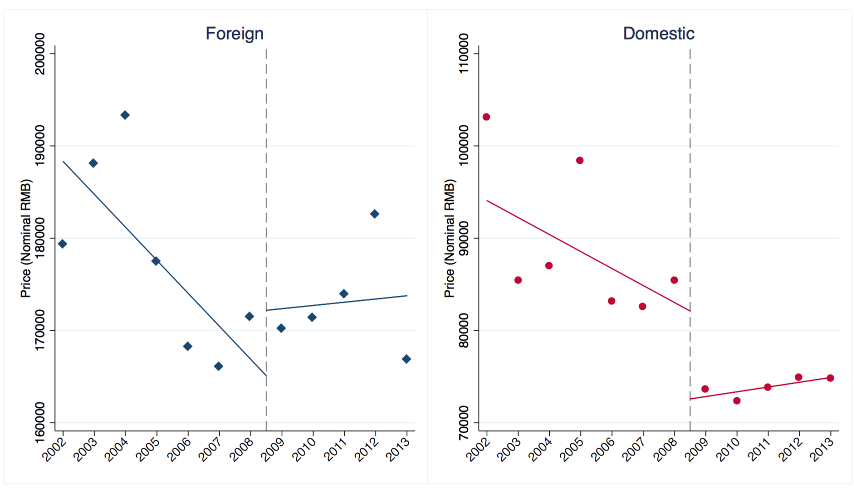
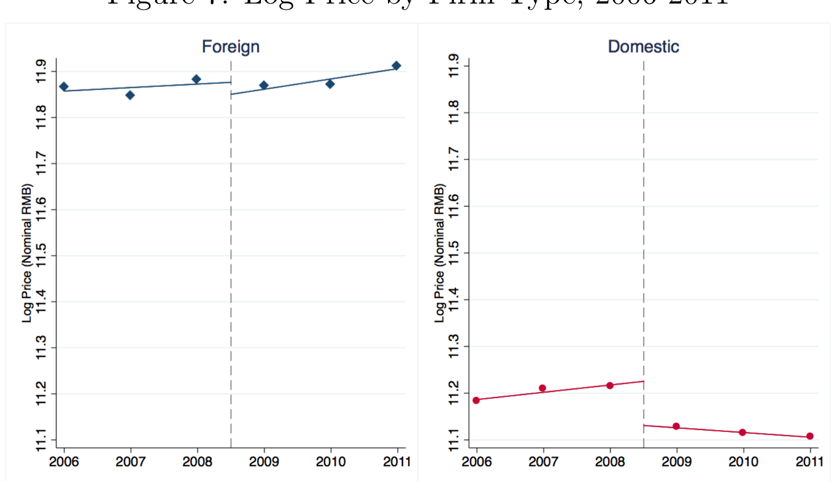


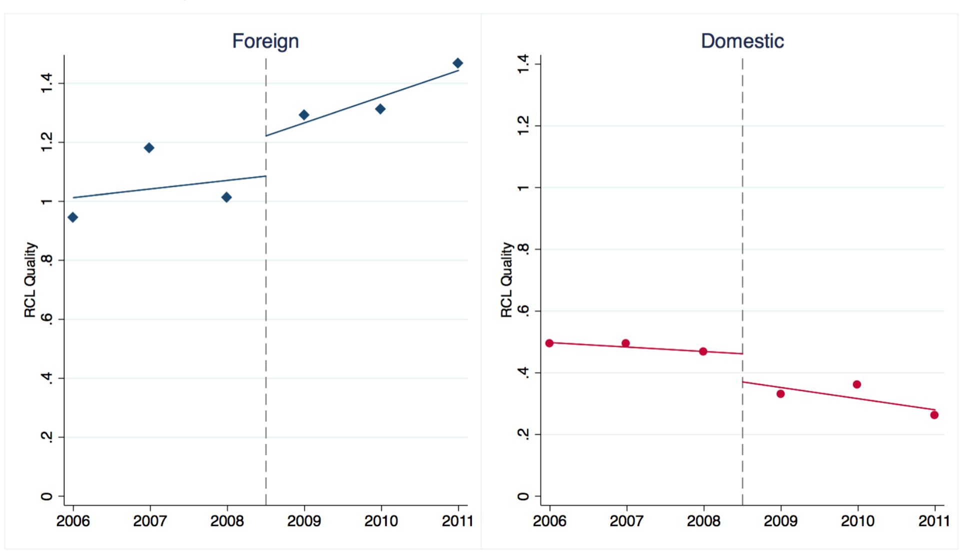
Figure 6: Log Torque by Firm Type, 2006-2011

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



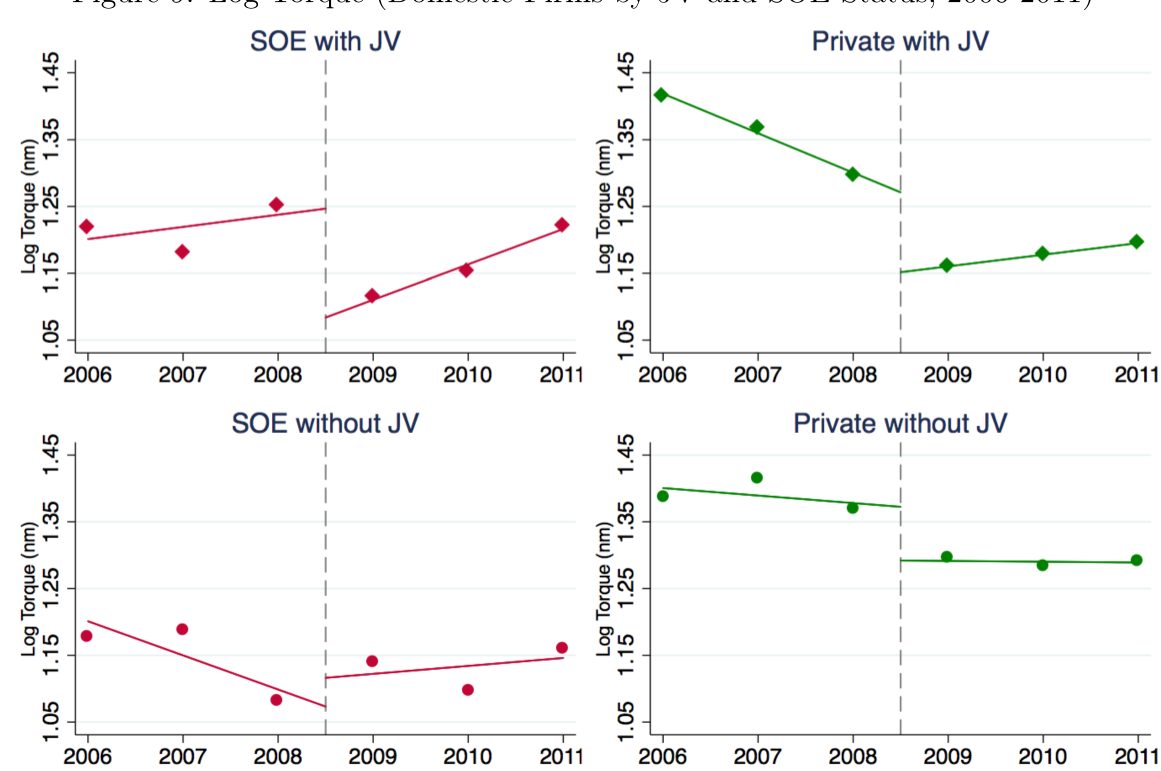
Note: Figures 5-7 show binned scatterplots of price, log torque, and log price by firm type.

Figure 8: RCL Quality by Firm Type, 2006-2011



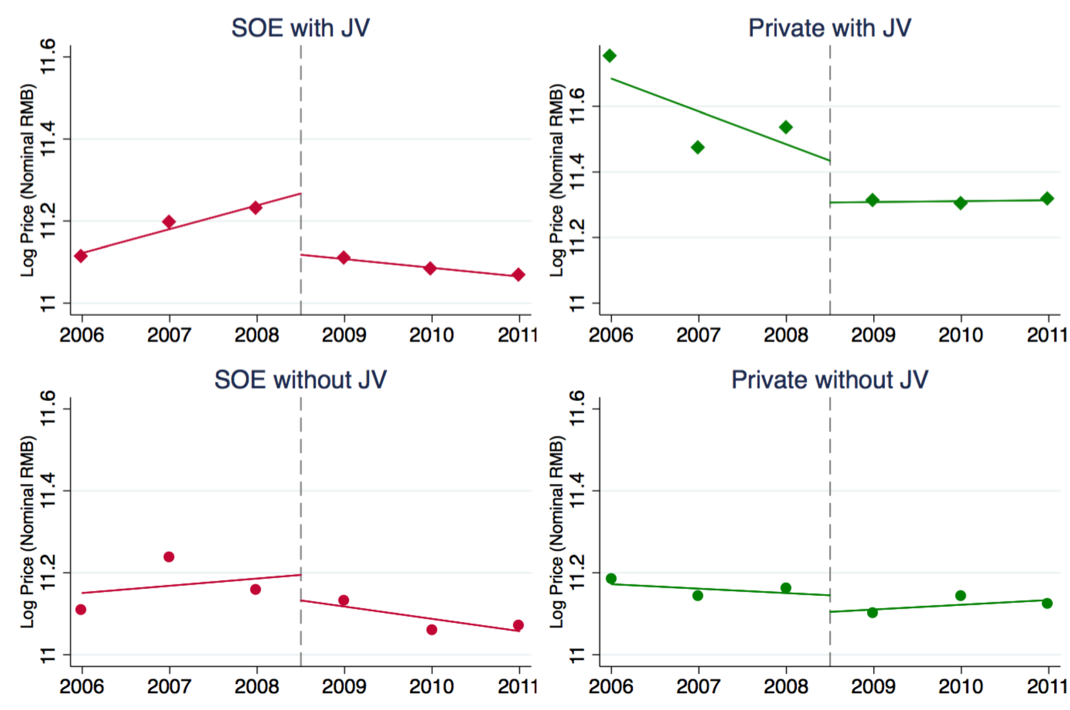
Note: This figure shows binned scatterplots of quality measured as the residual in the representative consumer logit model, by firm type.

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



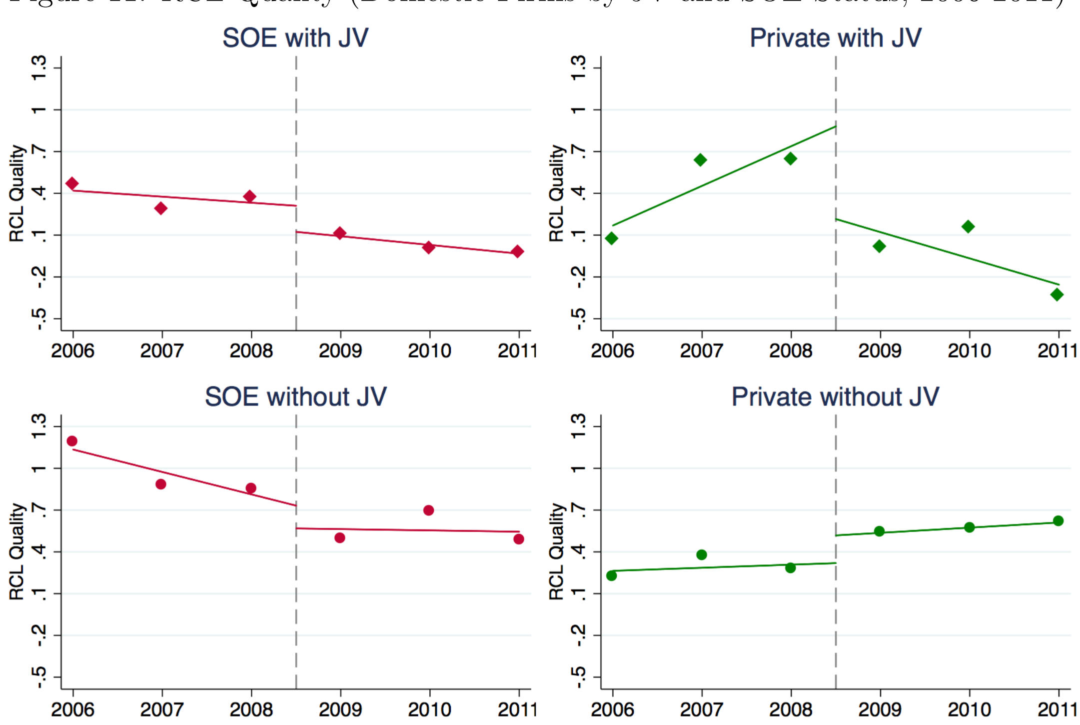
Note: This figure shows binned scatterplots of log torque for domestic firms, by JV status and ownership type.

Figure 10: Log Price (Domestic Firms by JV and SOE Status, 2006-2011)



Note: This figure shows binned scatterplots of log price for domestic firms, by JV status and ownership type.

Figure 11: RCL Quality (Domestic Firms by JV and SOE Status, 2006-2011)



Note: This figure shows binned scatterplots of quality measured as the residual in the representative consumer logit model, by JV status and ownership type.