Joint Ventures and Technology Adoption:

A Chinese Industrial Policy that Backfired

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Abstract

In developing countries, governments often mandate joint ventures (JVs) between foreign and domestic firms to spur technology transfer. Through knowledge spillovers, JVs should reduce the cost of technology acquisition. Yet a version of the Arrow replacement effect may discourage innovation in JVs. Which of these opposing forces dominates is an empirical question that I address with novel data on China's auto sector. Recent fuel economy standards provide plausibly exogenous variation in the fixed cost of quality upgrading for domestic (Chinese) firms. In a difference-in-differences design, I show that relative to foreign firms, domestic firms reduce quality and price in response to the standard, rather than invest in fuel efficiency technology. Domestic firms with JVs reduce quality the most; the negative JV effect outweighs the negative state ownership effect. Consistent with a cannibalization channel, the effect is stronger when firms compete more intensively with their partner. The results suggest that 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,] "Once you've had it you will get addicted forever...From central authorities to local governments, everyone has been trying hard to bring in foreign investment. But so many years have passed and we don't even have one brand that can be competitive in the auto world."
– Reuters (2012) quoting He Guangyan, Former Chinese Minister of Machinery & Industry.

I. Introduction

This paper explores how an industrial policy designed to induce technology transfer can backfire, perversely disincentivizing technology acquisition. Developing countries often require foreign entrants to form joint ventures (JVs) with domestic firms. In theory, JVs give domestic partners more access to foreign R&D and manufacturing processes, which reduces 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. The domestic firm is discouraged from investing in substitutes to its foreign partner's products, lest it cannibalize its rents from foreign firm sales. Such cannibalization is similar in spirit to the Arrow (1962) replacement effect, which deters monopolists from innovating. Pushing in the opposite direction is an adaptation of the Gilbert and Newbery (1982) efficiency effect, where the JV reduces the cost of technology acquisition These countervailing forces exist independently of the foreign firm's efforts to deny or encourage technology transfer. Whether JVs cause domestic firms to innovate more or less is an empirical question; the answer depends on whether the negative effect of foreign partner profits outweighs the positive effect of lower technology acquisition cost.

As a case study, I focus on China's automotive industrial policy, which has called for globally competitive, high-quality Chinese firms since the late 1970s.[1] The cornerstone of this policy is a mandate that foreign entrants produce via JVs with domestic firms. The

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

following example illustrates the JV structure during the period I study, from 1999 to 2013. BMW manufactures in China through its JV with Brilliance Auto, a privately-owned Chinese firm. The two companies' JV plant produces only BMW vehicles. Brilliance helped finance the JV plant and receives fifty percent of profits from sales of BMWs manufactured in China. Brilliance produces its own brands at other plants where BMW is not involved.

Foreign brands like Volkswagen, GM, and Toyota have consistently dominated the local market in quality, price, and market share. Nearly all foreign brand vehicles are produced in China through JVs, as high tariffs have precluded large-scale imports. The failure of China's auto industrial policy to produce brands that can compete even domestically is a puzzle that goes beyond the inefficiencies associated with state ownership. Although evaluating the effect of JVs on innovation is challenging, it is globally relevant. Brazil, Mexico, India, Nigeria, and Malaysia have mandated JVs, and China pressures foreign entrants to form JVs in other sectors.[2]

China's sudden and stringent 2009 fuel economy standards provide plausibly exogenous variation in the fixed cost of technology upgrading.[3] An automaker facing fuel economy standards can either add fuel efficiency technologies or reduce quality by decreasing power and/or weight. That is, standards compel more advanced technology in heavier and more powerful vehicles, which also garner the highest profit margins for multinational automakers. The fuel economy policy imposed a fixed cost disadvantage on domestic firms. Foreign firms like BMW, which already faced such standards elsewhere, incurred only the variable cost of including their efficiency technologies in local production.

In a difference-in-differences design, I treat foreign firms as a control. I show that while they continued on an upward trajectory, China's standards led domestic firms with JVs (like Brilliance) to reduce quality and price, without gaining market share. The critical assumption is that foreign firm technology transfer behavior did not change immediately around the policy.

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

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

I use novel, reliable, comprehensive model-level sales and characteristics data for the Chinese auto market. Relative to foreign firms, the policy reduced domestic model price by 15%, torque (a measure of acceleration and power) by 11%, and weight by 5%. The effect is measured within firm and conditional on model sales volume. I confirm the main results 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 bandwidths around the policy, parallel trend demonstration, and varying fixed effects.

I disaggregate the standards' impact along two dimensions: whether the 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 JV's than among SOEs. If a cannibalization threat disincentivizes innovation, the effect should be larger among domestic firms that compete more intensively with their partner. I find this to be true using the pre-policy vehicle class share and price distributions as proxies for competitive intensity. 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 encourage domestic firm innovation. I find that both had precisely the opposite effect. I cannot assess whether the post-fuel economy policy decision to go down-market was profit maximizing. Regardless, it contrasts with the government's intentions. My 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.[4]

[4]On (a), see Chen, Jiang, and Ljungqvist (2015), Fang and Lerner (2015), Allen et al. (2005), Khandelwal,

This analysis is limited in two ways. First, it addresses only short term responses to a technology cost shock. In the longer term, some domestic firms are likely to invest in innovation; my results suggest these will most likely be private firms without JVs. Second, the cannibalization channel that I propose may be at play among JVs more broadly, but it is not obvious that my empirical results generalize to voluntary JVs or those in which partners have similar technical capacity. While my results may not apply to alternative contractual relationships, they indicate how challenging it is to contract knowledge spillovers.

Technology diffusion is central to economic development (Lucas 1993, Young 1991). 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.[5] 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). I present causal evidence of an industrial policy failure. In my setting, the most innovative firms are the least touched by industrial policy.

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

Schott and Wei (2013), and Lin, Liu and Zhang (1998). On (b), see Ramachandran (1993), Moran (2002), and Urata and Kawai (2000). However, other studies find evidence of positive spillovers from JVs, like Javorcik (2004) and Dimelis and Louri (2002).

[5]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 and Mathews 2002) and negative effects (Inkpen and Crossan 1995, Doner 1991). The literature on FDI in China has not addressed domestic partner learning (Du, Harrison and Jefferson 2011, Lin et al. 2009, Xu 2008).

foreign technology licensing and reverse engineering.

Despite a rich theoretical literature, it has been challenging to evaluate the efficacy of industrial policies that target technology upgrading.[6] I depart from much of the past literature by using technical quality, rather than production functions and accounting-based productivity measures. Firm-level panel data is also relatively rare in the literature on technological capacity and innovation, which has relied on aggregates, case studies or cross-sectional survey data, particularly for the developing world (Fagerberg, Srholec and Verspagen 2010, Figueiredo 2006). 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 (Aitken and Harrison 1999, Blalock and Gertler 2007), and evaluations of subsidy programs (Rotemberg 2015, Howell 2015).

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

II. 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.[7] The most recent automotive sector plan states that "Development of the automobile industry, including transformational upgrading,

[6]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.

[7]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).

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, so a JV was the door to China's market for a foreign firm.[8] The JV is a stand-alone enterprise producing only foreign brand cars. The foreign partner owns no more than 50%, and usually also retains 50% of profits. The foreign firm designs, controls, and operates the plant. Beyond the 50-50 division of profits, there is unfortunately no information available about specific contractual relationships. The government initially handpicked domestic partners - all of which were state-owned - but after WTO accession retreated to approving JVs (Richet and Ruet 2008). Many large Chinese firms now have multiple JVs with different foreign firms. Also following WTO accession in 2001, the government removed barriers to entry for private firms. Today, domestic Chinese auto manufacturers exist along two axes: whether or not they are state-owned, and whether or not they have JVs with foreign firms.

In negotiations to establish initial JVs in the 1980s, foreign firms benefited from information asymmetry about auto manufacturing, and bounded potential technology transfer by producing only outdated models (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).[9] 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

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

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

of useful technology, its China JV research center was largely used to tweak existing GM models for the Chinese market (Tang 2012). Foreign firm behavior is not the focus of this paper, but it appears to be consistent with Branstetter and Saggi (2011), who theorize that stronger intellectual property rights reduce imitation risk, increasing FDI and innovation incentives.

The 1994 directive and similar policies were unenforceable. Instead, competition compelled foreign firms to produce the latest models in China by the mid-2000s. Between 2000 and 2013, the number of foreign firms producing in China through JVs increased from 4 to 17. As in other sectors, SOEs were corporatized, largely separated from direct government control, and often partially listed on stock exchanges (Andrews-Speed 2012). 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.

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. Domestic firms produce low quality, low price models. There is ample anecdotal evidence from the popular press that JVs failed to achieve technology transfer; and domestic firms did not develop innovation and design capability.[10] 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" (Dunne 2012). 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

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

incentive to build their own brands."

The literature on China's economy has focused on the efficiency of SOEs relative to private firms.[11] However, it is not obvious that n some high-tech sectors, firms with at least 50% state-ownership have become globally competitive, dominating the domestic market and achieving meaningful exports.[12] Hsieh and Song (2015) show that in the 2000s SOEs had faster 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.

III. Incentives to Innovate in Joint Ventures

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

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

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

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 $\frac{\partial p_i}{\partial \phi_i} > 0$,

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

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

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

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

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

The foreign firm's profit decreases in a competitor's quality $\left(\frac{\partial \pi_{JV}^{foreign}}{\partial \phi_i} < 0\right)$. Thus the domestic firm's investment in own quality reduces its marginal profit from the JV.[13] 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. 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.[14]

Countering the ARE is what Gilbert and Newbery (1982) call the "efficiency effect." Suppose the cost of acquiring fuel efficiency technology is $F_j(\phi_i)$, so that $C_i = \mathcal{F}(\cdot, \phi_\text{i} + \text{F}_\text{j}(\phi_\text{i}))$.[15] The monopolist is assumed to be more efficient in making profits than a

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

[14] 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.

[15] I assume the cost of fuel efficiency technology is fixed and additive, though it need not be. 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.

duopoly, so its preemptive payoff is larger than the entrant's. The parallel assumption in the JV context is that domestic firms with JVs have a lower $F_{j,JV}$. Firms with JVs have greater access to foreign firm technology than firms without JVs, so $F_{j,JV} \leq F_{j,No\ JV}$. Holding other aspects of the cost function fixed, I assume that increasing quality is at least as costly for firms without JVs as for firms with JVs, or $\frac{\partial C_{i,JV}}{\partial \phi_i} \leq \frac{\partial C_{i,No\ JV}}{\partial \phi_i}$. Investment in fuel efficiency technologies is incremental and relatively certain. In the Gilbert and Newbery version of the model, this setup will make the preemptive payoff higher and the efficiency effect dominant. The foreign firm already possesses the technology, so $F_{foreign} = 0$.

In the empirical analysis, I observe a plausibly exogenous increase in $F_j(\phi)$. 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 outweighs the positive effect of a lower technology acquisition cost (efficiency effect). If the cannibalization (ARE) effect dominates, then:

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

Note that the three terms on the left are negative, and the ∂C terms are positive (these sum 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 $\frac{\partial \pi_{JV}^{foreign}}{\partial \phi_i}$).

IV. 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.[16] Automakers can meet new standards without new technology by building lighter, less powerful cars. Margins for adjustment that reduce quality rather than include new technologies included 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.[17] Heavier and more powerful vehicles generally have higher profit margins than other segments (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.[18] Phase 2 came into effect in January 2008 for new

[16]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).

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

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

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 (Table A1 lists the standards by weight class, and Figure A2 compares standards across countries).[19] 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.[20] 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).[21] 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 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 Figure A3).[22]

V. Data and Descriptive Statistics

This paper is based on novel, comprehensive, model-level data of light-duty passenger vehicle sales in China between 1999 and 2013. The data is from the State Council Development

[19]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.

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

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

[22]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.

Research Center, which conducts analysis for China's top-level State (i.e. not Party) governing apparatus. The data is quite reliable, as it originates in police registration data.[23] Each observation is a new model-year, such as the 2010 Volkswagen Jetta. The data includes - in Chinese - the ultimate Original Equipment Manufacturer (OEM), brand, model name, vehicle class, engine displacement, and power train.[24] The data is national, so I am unable to analyze regional variation.

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).[25] Descriptive statistics at the model-year level, sorted by firm type, are in Table 1.[26] Figure 1 shows that sales increased from under 1 million units in 1999 to 16 million units in 2013; the foreign market share declined from about 80% in 1999 to 60% in 2006. Since the 2009 policy, domestic firm market share declined somewhat from about 45% to 39% (these figures exclude imports). Variety increased as well; the number of models increased linearly from 23 in 1999 to 426 in 2012.

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

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

[24]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.

[25]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.

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

RMB. When weighted by sales within firm, it declines to 122,000 RMB, or almost $17,000.

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 a useful indicator of technical quality.[27] 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. Horsepower is torque multiplied by a given speed (rotations-per-minute, or RPM), and determines the top speed of the vehicle. A model's advertised torque is the maximum achieved at a particular RPM. More power at lower speed is better, so lower RPM is indicative of higher quality. The metric used in regression analysis is maximum torque divided by the listed RPM.[28]

I restrict analysis to 3,177 models with sales of at least 1,000 units, of which I have price for 3,128, torque data for 2,726, and weight for 2,643. (In the analysis I exclude firms with sales of less than 1,000 units as these are not typically legitimate models, but are rather aimed to be showroom models or token alternative fuel efforts.) Table A2 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 Figure A4.

I use brands as the unit of analysis in descriptive statistics and primary estimations. Examples of brands are Ford, Audi, BYD, and Roewe. Top brands are graphed in Figure 2 for 2003, 2008 and 2013. The graphs show how Chinese brands have proliferated, while

[27] Torque is the amount of force the engine can apply in a rotational manner, measured in nanometers.
[28] I then multiply by 100, because in native units RPM is about 2 orders of magnitude larger than torque.

their sales-weighted dollar prices have actually decreased. VW remains the largest foreign producer by sales volume, but its dominant position in 2003 has eroded. The graphs show that despite their lower prices, Chinese firms do not dominate at the low end of the market.

To avoid confusion, I term brands "firm," but the reader should be aware that in many cases the firms I refer to are in fact subsidiaries of an OEM. While Ford and BYD are both their respective OEM's only brand, Audi is a Volkswagen subsidiary, and Roewe is a SAIC subsidiary. I use brands because they are the unit of observation most relevant to 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.

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 in each type by year. My estimation relies on the small number of SOEs without JVs and private firms with JVs (four to six and three, respectively).[29] Table A3 replicates Table 1 among domestic firms, dividing them by JV and SOE status. Among SOEs there are 797 model-years, compared to 486 for private domestic firms. Among SOEs with JVs there are 456 model-years, compared to 82 for domestic private firms with JVs.

Empirically, exporting is strongly associated with firm productivity and competitiveness.[30] Chinese central government policy also explicitly targets auto exports (State Council 2009). Total exports remained small in 2012, at 0.6 million vehicles. Although exports are increasing, they remain far from meeting government targets (Roland Berger 2013). Since 2008, private firms and local SOEs without JVs have been responsible for almost all passenger vehicle exports, depicted in Figure 4.[31] Between 2008 and 2012, private firms without JVs

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

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

[31] 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.

exported 10-20% of their total sales, and local SOEs without JVs exported 10-30%, though essentially none of these 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).

VI. Empirical Strategy

In a difference-in-differences (DD) design, I compare foreign and domestic firms' model characteristics before and after the 2009 fuel economy policy. The standard DD design involves two groups, one of which is subject to a treatment in the second of two time periods. If the two groups are ex-ante similar and have similar time trends, then inclusion of controls for treatment and state should yield an estimated coefficient on the treated state that is the average difference between the treatment group and the control group. The fuel economy policy, which put domestic firms at a fixed cost disadvantage in technology upgrading, is the treatment. Foreign firms are the "control;" they already possessed fuel efficiency technology. However, since the policy applied to all firms, the estimated treatment effect is best interpreted as the difference in responses across firm types.

DD estimators pose two potential problems. First, the design fails if the policy is endogenous to the group studied. The fuel economy standard affected both foreign and domestic firms, and I have not found other policies or market structure changes in the period analyzed that affected only domestic firm production. Second, serial correlation in variables may cause downward bias in the standard errors, especially with a relatively long time series and DD implementation via time fixed effects. Pooling the data on either side of the treatment and clustering standard errors by group rather than time solves the problem, particularly when the number of groups is large.[32]

I first estimate the following regression:

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

The coefficient of interest β is the effect of the policy on domestic firms relative to foreign firms.[33] 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.

The indicator Policy_t is 1 if the year is 2009 or later, and 0 otherwise. The indicator Domestic_j is 1 if the firm is Chinese (such as BYD or Chery), and 0 if it is foreign (such as Nissan or GM). I use $\gamma_2\text{Domestic}_j$ when I exclude firm fixed effects. With firm fixed effects, it is not identified. In the primary specification with firm fixed effects, all variation is within firm, and a minor car with odd characteristics cannot bias the results. In the primary specification I use a bandwidth of three years on either side of the policy, condition on sales volume, and include firm fixed effects.[34] The parallel trends assumption - that the error term is uncorrelated with the other variables - is not directly testable, but I present evident to support it in Section 8. In Section 8, I also exploit the staged policy for new and continuing models in a triple-difference specification. As firms can form new JVs there may be concern about selection into treatment. Although the industry is changing rapidly, Figure 3 shows that there is relatively little entry and exit into and out of categories in the three years around the 2009 policy.

I alter the main specification to test predictions from Section 3. First, I interact the

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

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

[34] Also, I require models to have sales volume of at least 1,000 vehicles.

policy effect with firm 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 policy effect on firms that have JVs but are private, and firms that are SOEs but do not have JVs.

$$\begin{aligned}Y_{it} \quad = \quad & \alpha + \beta_1 \left(\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j\right) + \beta_2 \left(\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{Has JV}_j\right) \\ & + \beta_3 \left(\text{Policy}_t \cdot \text{Domestic}_j \cdot \text{SOE}_j\right) + \beta_4 \left(\text{Policy}_t \cdot \text{Domestic}_j\right) \\ & + \beta_5 \left(\text{Domestic}_j \cdot \text{Has JV} \cdot \text{SOE}_j\right) + \gamma_1 \text{Policy}_t \left[+\gamma_2 \text{Has JV}_j\right] + \gamma_3 \text{SOE}_j \\ & + \gamma_4 \text{Sales Volume}_i + \left[\mathbf{1} \mid \text{Firm/Model/Class} = j/i/k\right] + \varepsilon_{ijt}. \qquad (7)\end{aligned}$$

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. The model predicts that the negative effect should be loaded on firms with JVs; if this outweighs any negative effect of being an SOE, then β_2 should be larger in magnitude than β_1. Second, I omit foreign firms to examine the effect of the policy when $\text{Domestic}_j = 1$. The model predicts that the negative effect of the policy on vehicle quality should be stronger for firms with JVs. While this approach lacks the strength of the foreign firms as "control," it provides a clearer test of the model.

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 vehicle class and market segment. The first proxies for pre-policy competition are the SUV and minivan share of a firm's sales. I sum a firm's annual minivan/SUV sales and divide it by total sales, then take the pre-policy mean and identify a firm as a minivan/SUV producer if it is non-zero/more than 50% (most firms do not produce minivans at all). I then estimate Equation 6 on the subsample of partner firms competing in the same class. An example of such a pair for SUVs is BAIC ("Beiqi") Zhanqi and partner Hyundai. For minivans, an example is Jiangling Motors (JMC) Landwind and partner Ford. The point is that the cannibalization effect should be smaller if the foreign partner produces mostly sedans while the domestic firm produces mostly minivans.

Second, the cannibalization channel should be larger in down-market segments, since there are effectively no Chinese models competing in the luxury market. I segment the sample in two ways. I estimate Equation 7 limiting the sample to models that are below median price, torque, and weight. Also, I omit firms whose partners produce *only* produce high-end vehicles. Specifically, I exclude partners of BMW and Mercedes-Benz (Beiqi, Beiqi Weiwang, Zhanqi, Brilliance).

VII. Results

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

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

Estimates of Equation 6, using a three year window on either side of the policy, are in Table 2. The standards reduced torque in domestic models relative to foreign models by 11%. They reduced price by 15%, and weight by 65 kg, or about 5% of the mean. All are significant at the 1% or 5% levels.[35] There is still a significant, although smaller, negative effect on torque with model fixed effects (Panel 1 column IV). Firm and class (SUV, minivan, sedan) fixed effects yield roughly similar results to the main specification (Panel 1 columns V-VI).

If domestic firms reduced price to gain market share in certain segments, the effect of the policy should disappear when I control for sales volume. Panel 2 columns I-III shows that the effects are roughly the same. The effects become larger and more significant when I expand the bandwidth to all years (1999-2013), in Panel 2 columns IV-VI. This provides reassurance that domestic firms did not catch up to foreign firms in 2012 and 2013, despite the increasing trend from Figure 6.

Equation 6 is estimated within subsamples of domestic firms in Table 3. When only domestic firms with JVs are included (column I) along with all foreign firms, the negative effect of the policy is stronger, at -16% for torque, -23% for price, and -100 kg for weight. These are significant at the 1%. Among SOEs and SOEs without JVs (columns II and III), the effects are smaller, but mostly still significantly negative and slightly higher than the full sample effects in Table 2. Among private firms with and without JVs (columns IV and V), the coefficients are insignificant for all characteristics, but near zero for private firms without JVs.

To establish whether these coefficients are significantly different from one another, I estimate Equation 7 in Table 4. 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

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

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 only for the JV interaction. Columns II, IV, and VI condition on sales volume. This makes the weight effect insignificant. Panel 2 limits the sample to domestic firms. The strategy here is to compare 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.

I examine pre-policy competition intensity in Tables 5 and 6. Table 5 columns I-III limits the sample to the bottom half of the market, considering only models with below-median price, torque, and weight, respectively. The effects increase significantly, to -23% for torque and price, and -71 kg for weight. Columns IV-VI omit domestic firms with high-end partners. The effects on price and torque are again stronger than in the main specification, and the effect on weight increases dramatically to -196 kg. Table 6 Panel 1 includes only the subset of JV partners whose sales were majority SUVs in the three years before the policy.[36] The effects are larger than in the primary specification, at -25% for torque, -19% for price, and -189 kg for weight, significant at the 1%, 10%, and 1%, respectively. Conditioning on sales (columns IV-VI) causes the effect on price to lose significance. In Panel 2 I examine partners that produced minivans before the policy, and here I find stronger and highly significant effects for all three characteristics, including specifications that condition on sales. The effects conditional on sales are -18% for torque, -21% for price, and -106 kg for weight, all significant at the 1% level. It is clear that when partners produced nearer-substitutes pre-policy, the fuel economy standards caused a more extreme reduction in quality and price. This lends support to the cannibalization channel.

In sum, the adverse technology cost shock reduced the equilibrium quality choice for firms with JVs relative to those without JVs ($\phi_{i,JV} < \phi_{i,No\ JV}$). 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

[36] I do not use firm fixed effects in Panel 1 because the sample is so small.

in similar segments.[37] 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 innovation.

VIII. 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.

Parallel trends

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

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

In Table A4 Panels 1, 2, and 3, Type_j is 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. The $\hat{\beta}$ coefficients are

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

all near zero and insignificant. The time trend (continuous year variable) is mostly positive and slightly significant, reflecting some secular quality improvement before 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:

$$\begin{aligned} Y_{it} \;=\;& \alpha + \beta\left(\text{Policy}_t^{2008} \cdot \text{Domestic}_j \cdot \text{Continuing}_{it}\right) + \gamma_1\left(\text{Policy}_t^{2008} \cdot \text{Domestic}_j\right) \\ & + \gamma_2\left(\text{Policy}_t^{2008} \cdot \text{Continuing}_{it}\right) + \gamma_3\left(\text{Continuing}_{it} \cdot \text{Domestic}_j\right) \\ & + \gamma_4 \text{Policy}_t + \gamma_6 \text{Continuing}_{it} + (\mathbf{1} \mid \text{Firm} = j) + \varepsilon_{ijt}. \end{aligned} \tag{9}$$

The Policy_t^{2008} variable is 1 if the year is 2008, and 0 if 2007 or 2006 (two years are needed for an adequate sample). Here, β is the effect of being a continuing model relative to a new model, netting out the change in means in firm type (domestic vs. foreign) and in time period (after vs. before the 2008 policy).

Table 7 shows that in 2008, domestic firms' continuing models were more powerful, more expensive, and heavier than new models already subject to the policy, relative to the same comparison within foreign firms. 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.[38] Note that the coefficients on the individual indicators and interactions are not direct effects.[39]

[38] 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.

[39] 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

Additional robustness tests

This section focuses on key robustness tests of the main result for torque. Analogous tests for other characteristics and firm-type results are in the appendix. Table 8 Panel 1 columns 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. Column III omits fixed effects, instead including the Domestic_j individual effect. Column 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). Column V replaces the sales volume requirement of 1,000 units with 5,000 units. The main finding is intact in all these specifications.

Panel 2 columns I-III of Table 8 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.

IX. Conclusion

The conditions under 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. Conventional trade models like McGrattan

effect of being domestic, when the other two indicators and firm fixed effects are zero.

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 (2013) add China's requirement that foreign firms transfer technology in order to invest, they are much better able to match their model to moments in the data. They conclude that FDI decreases when foreign firms must transfer technologies and that Chinese firms prefer to appropriate the foreign capital 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 development of the auto sector in Japan, Taiwan, and South Korea. They featured an absence of FDI and little direct cooperation with foreign firms, but intensive licensing of foreign technology and reverse engineering.[40] Poorly designed industrial policy may help explain why China's auto sector development has differed so dramatically. A more rigorous WTO regime and tighter IPR protection may also have made it impossible in recent decades to replicate the earlier approaches.

Though Chinese firms may maximize profits, the absence of Chinese exports and the failure of Chinese firms to gain market share suggest that their down-market strategy has not thus far been successful. However, China's automotive industry is changing rapidly. New organizational structures, including independent engineering and design firms that allow domestic automakers to outsource R&D, may enable Chinese firms to undercut foreign competition for small, cheap cars in China and elsewhere. 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).

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

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

Table 2: Fuel Economy Policy Impact on Domestic Firms

Panel 1: Baseline specification

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

Panel 2: Conditional on sales

				All years (2002-2013)		
Dependent variable:	I. Log torque	II. Log price	III. Weight	IV. Log torque	V. Log price	VI. Weight
$\text{Policy}_t \cdot \text{Domestic}_j$	-.1**	-.15***	-60**	-.13**	-.22***	-91**
	(.047)	(.048)	(29)	(.055)	(.068)	(39)
Policy_t	.045**	.047**	37***	.12***	.0071	89***
	(.022)	(.022)	(13)	(.023)	(.027)	(16)
Sales Volume_i	-9.6e-07***	-1.5e-06***	-.00069***	-7.1e-07***	-1.3e-06***	-.00062***
	(3.2e-07)	(4.3e-07)	(.00024)	(2.6e-07)	(3.8e-07)	(.00019)
Firm f.e.	Y	Y	Y	Y	Y	Y
N	1643	1653	1599	2030	2060	1984
R^2	0.07	0.13	0.04	0.08	0.19	0.08

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:

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

Domestic_j is 1 if the brand is domestic (Chinese), and 0 if foreign. Policy_t is 1 if the year is 2009-11, and 0 if 2006-08. Sales volume is the number of units sold. 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 3: Fuel Economy Policy Impact on Domestic Firms (Sample Split by Firm Type)

Panel 1: Dependent variable is Log torque

Sample:	I. Firms with JVs	II. SOEs	III. SOEs without JVs	IV. Private	V. Private without JVs
$Policy_t \cdot Domestic_j$	-.16***	-.12***	-.13**	-.1	-.058
	(.061)	(.047)	(.051)	(.078)	(.093)
$Policy_t$	.038*	.037*	.037*	.039*	.039*
	(.022)	(.022)	(.022)	(.022)	(.022)
Firm f.e.	Y	Y	Y	Y	Y
N	1293	1377	1154	1281	1226
R^2	0.09	0.07	0.04	0.12	0.06

Panel 2: Dependent variable is Log price

Sample:	I. Firms with JVs	II. SOEs	III. SOEs without JVs	IV. Private	V. Private without JVs
$Policy_t \cdot Domestic_j$	-.23***	-.21***	-.19**	-.1	-.062
	(.066)	(.057)	(.076)	(.067)	(.074)
$Policy_t$	.03	.031	.023	.029	.029
	(.022)	(.022)	(.022)	(.022)	(.022)
Firm f.e.	Y	Y	Y	Y	Y
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:	I. Firms with JVs	II. SOEs	III. SOEs without JVs	IV. Private	V. Private without JVs
$Policy_t \cdot Domestic_j$	-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

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:

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

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. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 4: 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	
	I.	II.	III.	IV.	V.	VI.
$Policy_t \cdot Domestic_j \cdot Has\ JV_j$	-.16*	-.16*	-.2***	-.2***	-111*	-105
	(.083)	(.086)	(.052)	(.06)	(65)	(76)
$Policy_t \cdot Domestic_j \cdot SOE_j$	-.045	-.072	-.019	-.049	-24	-44
	(.063)	(.067)	(.056)	(.06)	(41)	(46)
$Policy_t \cdot Domestic_j \cdot Has\ JV_j \cdot SOE_j$	.12	.13	.12	.12	102	90
	(.095)	(.097)	(.088)	(.089)	(66)	(70)
$Domestic_j \cdot Has\ JV_j \cdot SOE_j$	-.14	-.09	-.26	-.19	-259**	-200
	(.23)	(.26)	(.22)	(.21)	(124)	(170)
Sale $Volume_i$		-9.7e-7***		-1.4e-6***		-6.9e-4***
		(3.2e-7)		(4.4e-7)		(.00024)
Domestic-Policy & individual effects	Y	Y	Y	Y	Y	Y
Firm & class f.e.	Y	Y	Y	Y	Y	Y
N	1643	1643	1653	1653	1599	1599
R^2	0.34	0.12	0.42	0.45	0.28	0.1

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

Dependent variable:	Log torque		Log price		Weight	
	I.	II.	III.	IV.	V.	VI.
$Policy_t \cdot Has\ JV_j$	-.18*	-.18*	-.16***	-.15**	-114	-109
	(.097)	(.096)	(.058)	(.058)	(85)	(81)
$Policy_t \cdot SOE_j$	-.11	-.096	-.054	-.021	-87	-72
	(.17)	(.16)	(.16)	(.15)	(120)	(113)
$Policy_t \cdot Has\ JV_j \cdot SOE_j$	.14	.17	.071	.089	104	114
	(.11)	(.11)	(.084)	(.088)	(82)	(79)
$Has\ JV_j \cdot SOE_j$	-.11	-.046	.095	.15	-111	-79
	(.2)	(.19)	(.17)	(.17)	(109)	(109)
Sale $Volume_i$		-1.1e-6*		-1.1e-06*		-.00062**
		(6.1e-7)		(6.3e-7)		(.00027)
Individual effects	Y	Y	Y	Y	Y	Y
Firm & class f.e.	Y	Y	Y	Y	Y	Y
N	628	628	624	624	596	596
R^2	0.23	0.31	0.04	0.13	0.22	0.28

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 7 in Panel 1. Panel 2 omits foreign firms and thus all non-identified terms from Equation 7. $Domestic_j$ 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. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

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

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

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 7. 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. Standard errors are robust and clustered by firm. †Domestic firms that have JVs with BMW or Mercedes-Benz omitted. *** indicates $p < .01$.

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

Panel 1: Domestic and foreign partners both produced primarily SUVs before policy

Dependent variable:	I. Log torque	II. Log price	III. Weight	IV. Log torque	V. Log price	VI. Weight
$\text{Policy}_t \cdot \text{Domestic}_j$	-.25***	-.19*	-189***	-.23**	-.16	-172***
	(.078)	(.099)	(55)	(.082)	(.098)	(55)
Policy_t	.019	.027	23	.032	.041	32
	(.038)	(.036)	(28)	(.037)	(.034)	(26)
Domestic_j	.26	-.63***	127	.27	-.62***	132
	(.18)	(.18)	(100)	(.16)	(.17)	(93)
Sales Volume_i				-1.3e-06***	-1.3e-06***	-8.3e-04***
				(4.1e-07)	(4.1e-07)	(.00029)
Firm f.e.	N	N	N	N	N	N
N	566	574	555	566	574	555
R^2	0.032	0.327	0.023	0.092	0.367	0.083

Panel 2: Domestic and foreign partners both produced primarily minivans before policy

Dependent variable:	I. Log torque	II. Log price	III. Weight	IV. Log torque	V. Log price	VI. Weight
$\text{Policy}_t \cdot \text{Domestic}_j$	-.17***	-.18***	-100**	-.18***	-.21***	-106***
	(.055)	(.059)	(43)	(.051)	(.059)	(39)
Policy_t	.041	.028	25*	.055**	.057**	36**
	(.027)	(.024)	(14)	(.028)	(.025)	(14)
Sales Volume_i				-1.2e-06***	-2.0e-06***	-.00087***
				(3.0e-07)	(4.1e-07)	(.0003)
Firm f.e.	Y	Y	Y	Y	Y	Y
N	856	864	837	856	864	837
R^2	0.08	0.3	0.03	0.16	0.4	0.11

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:

$$Y_{it} = \alpha + \beta\,(\text{Policy}_t \cdot \text{Domestic}_j) + \gamma_1 \text{Policy}_t\ [+\gamma_2 \text{Domestic}_j] + \gamma_3 \text{Sales Volume}_i + (\mathbf{1} \mid \text{Firm} = j) + \varepsilon_{ijt}$$

For the Panel 1 analysis, the sample is too small to include firm f.e., so I employ the Domestic_j indicator. Only domestic and foreign firms that have a JV, and for which the partner produces a similar distribution of vehicle class, are included. Policy_t is 1 if the year is 2009-11, and 0 if 2006-08. Sales volume is the number of units sold. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

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

	With firm f.e.			Without firm f.e.		
Dependent variable:	I. Log torque	II. Log price	III. Weight	IV. Log torque	V. Log price	VI. Weight
$\text{Policy}_t^{2008} \cdot \text{Domestic}_j \cdot \text{Continuing}_i$	.068*	.24***	129*	.19**	.22*	143**
	(.018)	(.021)	(31)	(.02)	(.066)	(21)
$\text{Policy}_t^{2008} \cdot \text{Domestic}_j$	-.086*	-.18***	-126*	-.2***	-.19*	-137**
	(.023)	(.017)	(34)	(.015)	(.057)	(26)
$\text{Domestic}_j \cdot \text{Continuing}_i$	.067	-.094*	-54	-.02	-.012	-65*
	(.024)	(.022)	(33)	(.02)	(.066)	(21)
$\text{Policy}_t^{2008} \cdot \text{Continuing}_i$	-.00015	-.055	-.72	.015	.029***	25
	(.02)	(.028)	(9.3)	(.012)	(.0015)	(34)
Policy_t^{2008}	.012	.034	5.8	.018*	.0086	-11
	(.0086)	(.021)	(13)	(.0053)	(.008)	(36)
Domestic_j				-.13**	-.67***	-3.3
				(.014)	(.057)	(26)
Continuing_i	-.072	.026	32*	-.064**	-.046***	-2
	(.027)	(.022)	(8.1)	(.0093)	(.003)	(35)
Sales Volume_i	-1.2e-06**	-2.0e-06*	-.0012**	-2e-06***	-2e-06**	-.0012***
	(2.4e-07)	(5.8e-07)	(.00024)	(2e-07)	(3e-07)	(.00011)
Firm f.e.	Y	Y	Y	N	N	N
N	636	646	626	636	646	626
R^2	0.579	0.692	0.562	.08	.29	.047

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 the number of units sold. Standard errors are robust and clustered by firm. *** indicates $p < .01$.

Table 8: Key Robustness Tests; dependent variable is 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 domestic firms. Observations *it* are new model-years. Estimates are variants of:

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

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 $p < .01$.

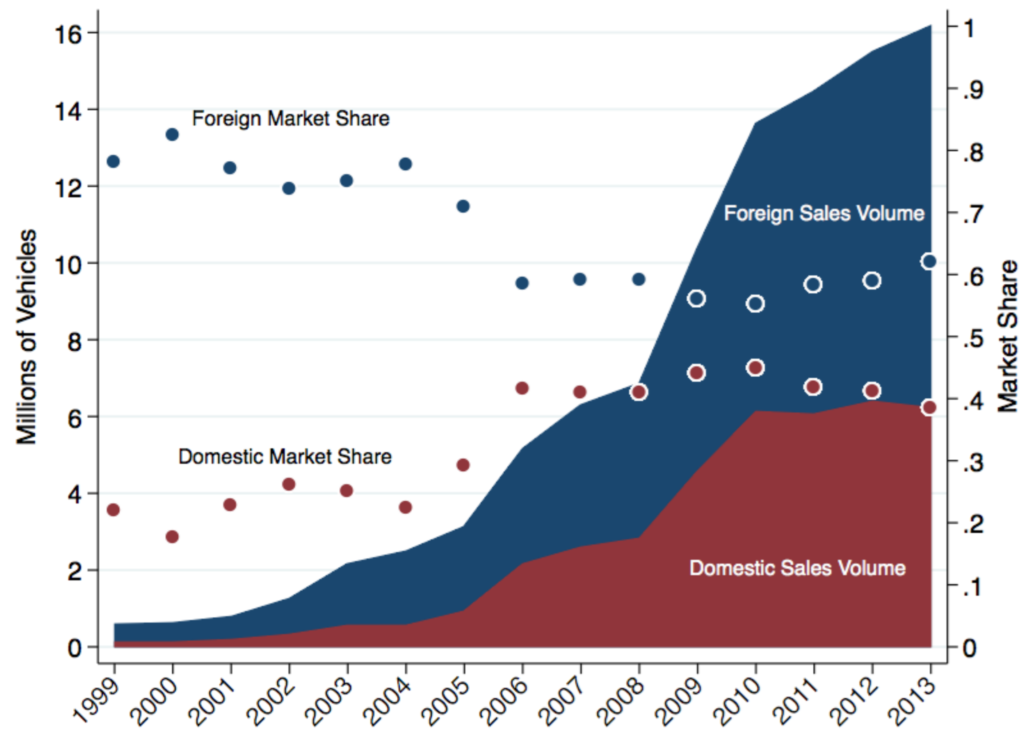

Figure 1: Sales Volume and Market Share by Firm Type

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.

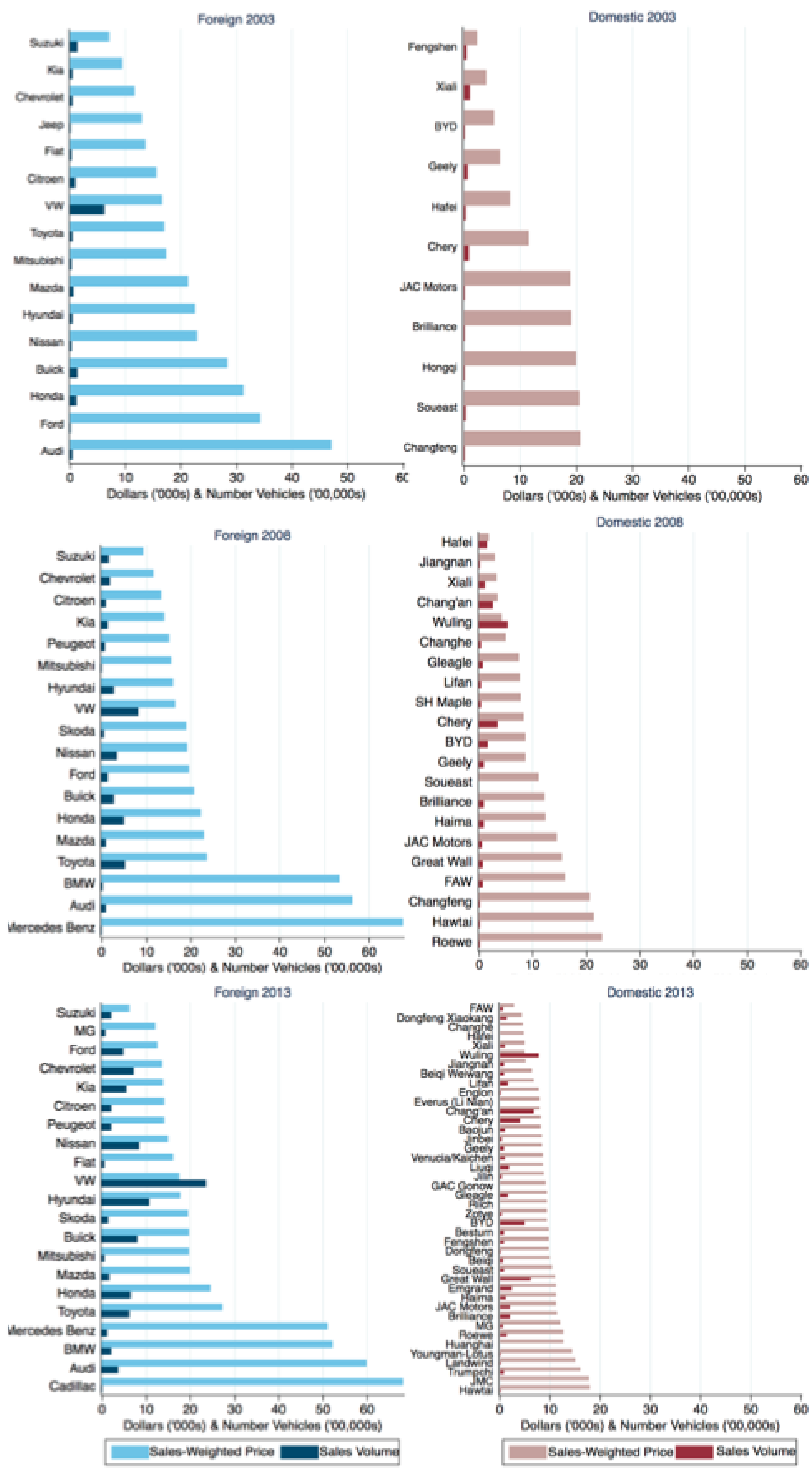

Figure 2: Sales Volume and Sales-Weighted Price by Firm

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

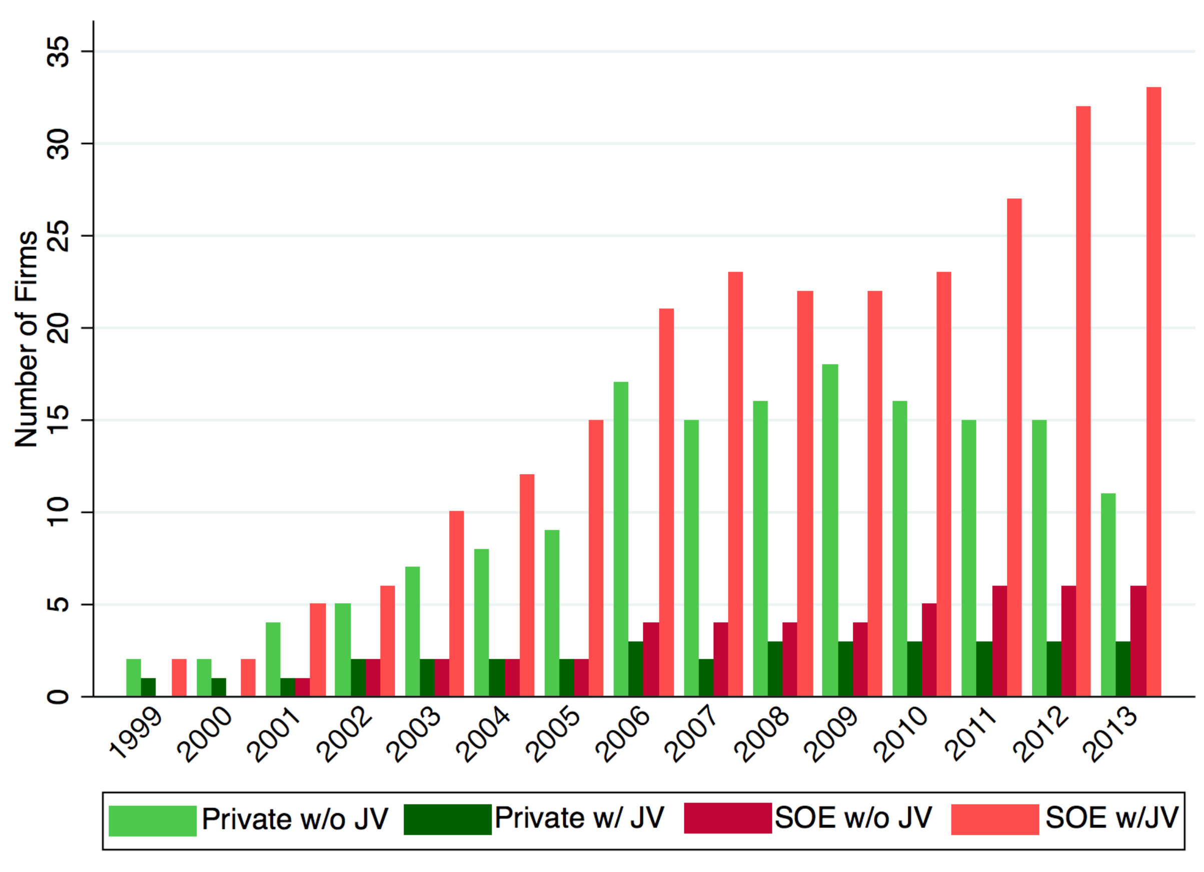

Figure 3: Number of Active Firms by Type

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.

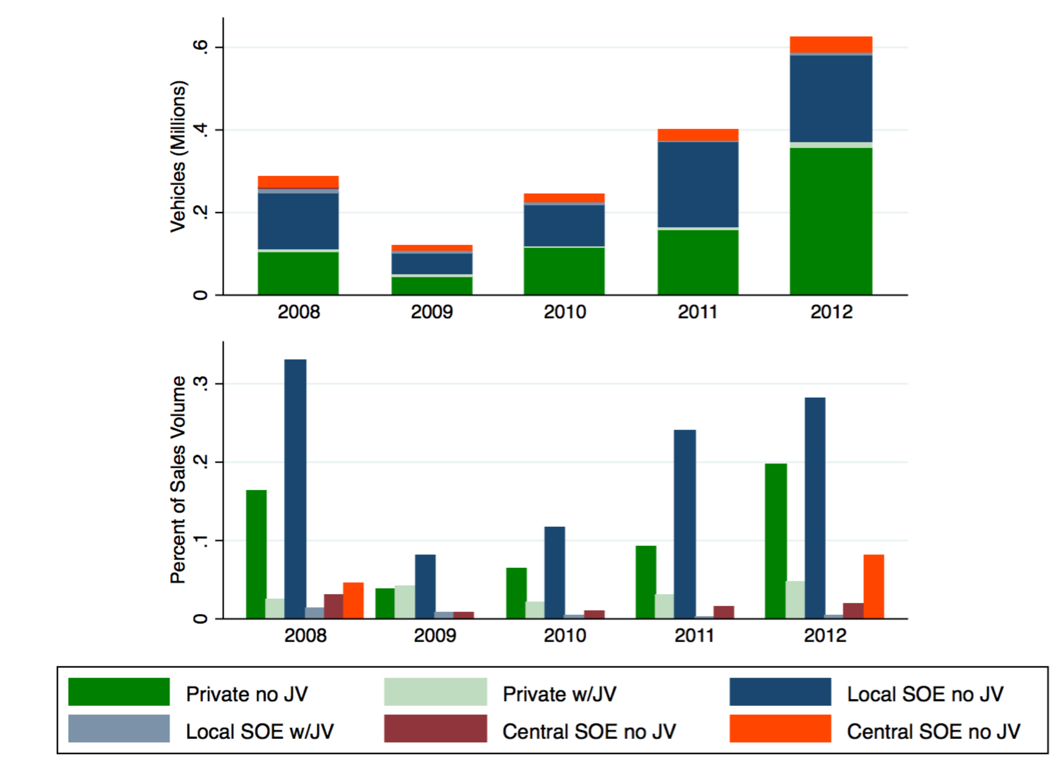

Figure 4: Domestic Firm Export Volume and Percent of Total Sales Volume 2008-2012
Note: This figure shows Chinese domestic firm vehicle exports. Top: exports by ownership type. Bottom: exported fraction of total sales volume. For example, the first green bar in the bottom graph is exports divided by all vehicles sold among all firms that are privately-owned and have no JV.

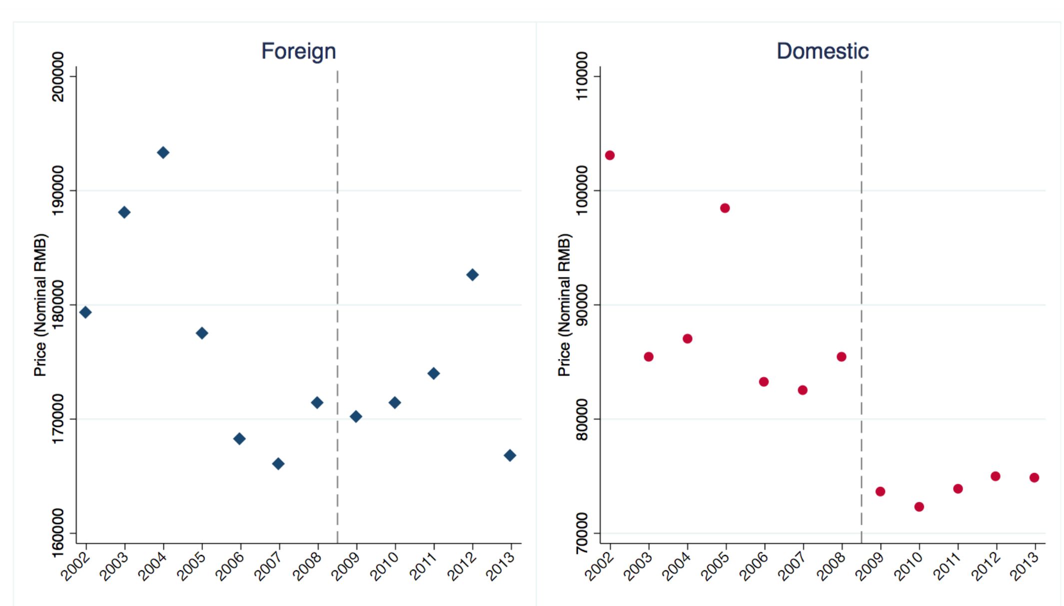

Figure 5: Price by Firm Type, 2002-2013
Note: This figure shows sales-weighted torque and price by firm type. Average taken across firms of each firm's average sales weighted characteristic.

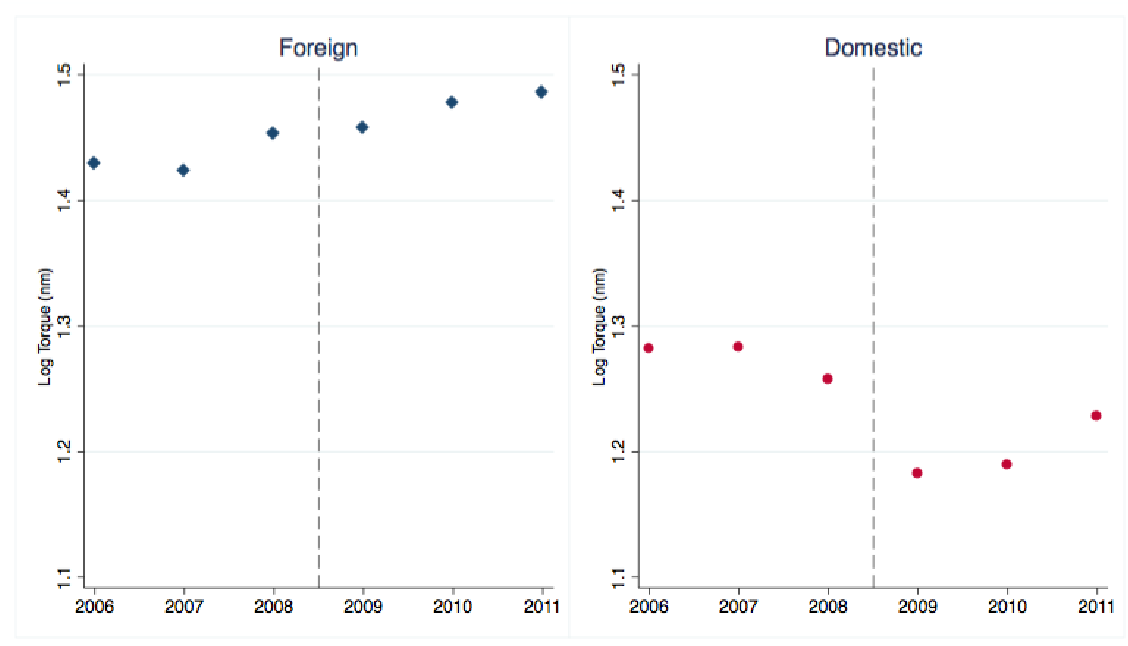

Figure 6: Log Torque by Firm Type, 2006-2011

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

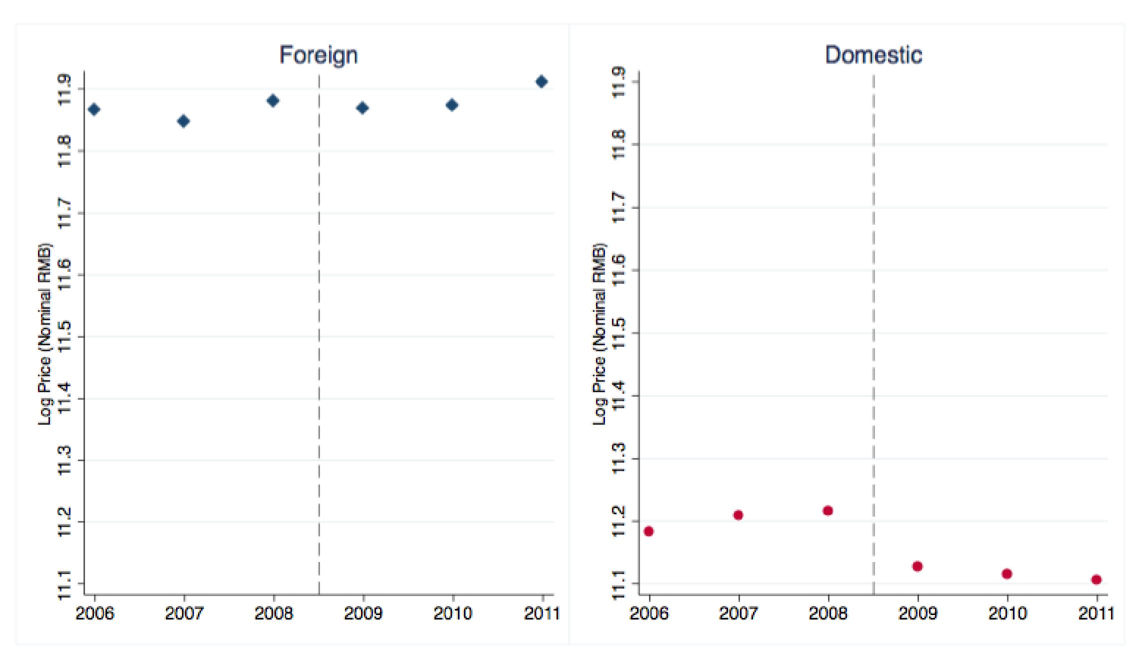

Figure 7: Log Price by Firm Type, 2006-2011

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

Figure 8: Log Torque (Domestic Firms by JV and SOE Status, 2006-2011)
Note: This figure shows sales-weighted torque and price by firm type. Average taken across firms of each firm's average sales weighted characteristic.

Figure 9: Log Price (Domestic Firms by JV and SOE Status, 2006-2011)
Note: This figure shows sales-weighted torque and price by firm type. Average taken across firms of each firm's average sales weighted characteristic.