Supply and Demand in the Chinese Automobile Market:
A Random Coefficients Mixed Oligopolistic Differentiated Products Model

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Abstract

We develop a random coefficients mixed oligopolistic differentiated products model of the Chinese automobile market that allows different consumers to vary in how much they like different car characteristics on the demand side, and that allows state-owned automobile companies to have different objectives from private automobile companies on the supply side. Our model incorporates two notable features of the Chinese automobile market: some automobile companies in China are state-owned, and some automobile companies in China form international joint ventures. We estimate our model using a comprehensive data set on the sales, prices, and characteristics of the majority of vehicle makes and models in China. Results show that while state-owned car companies may care somewhat about other objectives such as consumer surplus and alternative vehicle production, their primary objective is to make profits. Our results also provide evidence that Chinese automobile firms that form international joint ventures with firms in the U.S. and Japan have better technology. When comparing international joint ventures with car companies in the U.S. and Japan, the marginal costs of fuel efficiency and of alternative vehicles tend to be lower in joint ventures with Japanese firms, while the marginal costs of horsepower tend to be lower in joint ventures with U.S. firms. Results of counterfactual international joint venture simulations suggest that private firms, state-owned firms, the alternative vehicle market, and possibly consumers as well would all benefit if all of the automobile firms in China form international joint ventures with the U.S. or Japan.

Keywords: random coefficients, mixed oligopoly, state ownership, international joint venture, China, automobiles
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1. Introduction

China is experiencing rapid economic growth and, along with it, rapid growth in vehicle ownership. Evidence from Chinese cities suggests average annual growth rates in per capita vehicle ownership of 10% to 25% (Darido, Torres, and Mehndiratta, 2014). According to data from the China Statistical Yearbook, vehicle ownership increased by nearly 56 times between 1990 and 2011 (Liu and Lin Lawell, 2021); according to China's National Bureau of Statistics, the total number of civilian passenger vehicles owned in China increased from 17.35 million to 123.27 million from 2004 to 2014, with an annual growth rate of 21.69%. Privately owned passenger vehicles are the major contributor to the growth of the vehicle fleet (Deng, 2007). In 2009, China's automobile market became the largest in the world, surpassing the U.S. automobile market both in sales and production (Chen, Lin Lawell and Wang, 2020).

In this paper, we develop a random coefficients mixed oligopolistic differentiated products model of the Chinese automobile market that allows different consumers to vary in how much they like different car characteristics on the demand side, and that allows state-owned automobile companies to have different objectives from private automobile companies on the supply side. We apply our model to a comprehensive data set on the sales, prices, and characteristics of the majority of vehicle makes and models in China.

Our model incorporates two notable features of the Chinese automobile market. One notable feature of the Chinese automobile market is that Chinese automobile companies include both private automobile companies and state-owned automobile companies. Unlike private firms, state-owned firms may have objectives other than profit maximization alone. We therefore model the behavior of both private automobile companies and state-owned automobile companies in China; and allow for the possibility that state-owned car companies may possibly have different objectives from private car companies. We do not make any assumptions about whether or how much the state-owned firms care about objectives other than profit, but instead allow the data to tell us whether and how much state-owned firms care about these other objectives. In particular, we specify the utility function of state-owned firms as a weighted sum of several possible objectives, the weights for which we estimate econometrically.

A second notable feature of the Chinese automobile industry is that some Chinese automobile companies, both private and state-owned, form joint ventures with international car companies. One motivation for Chinese automobile companies to form joint ventures with international car companies is to benefit from the international car company's technology, and international car companies often have the key technology or control over the research and development in a joint venture (Hu, Xiao and Zhou, 2014). It is unclear whether the joint ventures benefit from better technology, however (Holweg, Luo and Oliver, 2009; Hu, Xiao and Zhou, 2014). Joint ventures with international car companies account for two thirds of the passenger vehicle market in China, with the rest mostly taken up by indigenous brands (Li, Xiao and Liu, 2015). We therefore use our model to analyze international joint ventures. In particular, we examine whether and how the marginal costs of technology-related vehicle characteristics are correlated with international joint ventures, which is a possible measure of whether Chinese automobile firms that form international joint ventures have better technology.

Figure A1 in the Appendix, adapted from Hu, Xiao and Zhou (2014), is a rough sketch of the market structure among some of the main firms in the Chinese automobile industry during the 2010-2013 time period of our study. Chinese firms that are at least 50% state-owned are in green. Private Chinese firms are in yellow. International car companies are in blue. Lines connecting firms indicate joint ventures between firms. The large boxes around state-owned firms and the international car companies with which they form joint ventures indicate the largest state-owned automobile groups in China.

According to Chinese automobile policy, a Chinese automobile company can form joint ventures with multiple foreign car manufacturers (Chen, Lin Lawell and Wang, 2020). For example, as seen in Figure A1 in the Appendix, Shanghai Auto has formed joint ventures with General Motors and Volkswagen. Dongfeng Motors has formed joint ventures with Nissan, Honda, Kia, and PSA. On the other hand, under Chinese policy, a foreign car manufacturer is only allowed to form joint ventures with up to two Chinese automobile companies.[2] For example, Honda has formed joint ventures with both Dongfeng Group and Guangzhou Auto. Toyota, another Japanese automobile firm, has formed joint ventures with both First Auto Work and Guangzhou Auto. In addition to large stated-owned auto groups, private car makers in China have also formed joint ventures with foreign car makers. For example, Huachen Auto has formed a joint venture with BMW.[3]

[2] According to "Chinese Automobile Industry Development Policy, 2009 edited edition": http://www.china.com.cn/policy/txt/2009-08/31/content_18430768_5.htm

[3] Further details about the Chinese automobile industry are provided in Chen, Lin Lawell and Wang (2020).

We innovate upon the previous literature in several ways. First, we develop a random coefficients mixed oligopolistic differentiated products model of the Chinese automobile market that allows different consumers to vary in how much they like different car characteristics on the demand side, and that allows state-owned automobile companies to have different objectives from private automobile companies on the supply side. An innovation we make upon the previous literature is that we model the behavior of not only private automobile companies but also state-owned automobile companies in China. Second, we analyze international joint ventures, a notable feature of the Chinese automobile market. Third, we develop a model of the Chinese automobile market that includes alternative vehicles so that cost and demand parameters relating to alternative vehicles can be estimated in addition to cost and demand parameters relating to gasoline-fueled vehicles. Alternative vehicles are vehicles that are powered by alternative fuel sources other than gasoline or diesel; and include hybrid cars powered on both gasoline and electricity, purely electric cars, plug-in hybrid cars, and extended range electric vehicles. Fourth, we use the parameter estimates to simulate the effects of counterfactual scenarios regarding state ownership and international joint ventures on firms, consumers, and welfare.

According to our results, consumers vary in how much they like different car characteristics. On the supply side, for the weights on different objectives in the state-owned firms' utility, we find that almost all of the weight (92%) is on profit. Thus, while state-owned car companies may care somewhat about other objectives such as consumer surplus and alternative vehicle production, their primary objective is to make profits.

Our results provide evidence that Chinese automobile firms that form international joint ventures with firms in the U.S. and Japan have better technology, while those that form joint ventures with international car companies from other countries do not. When comparing international joint ventures with car companies in the U.S. and Japan, the marginal costs of fuel efficiency and of alternative vehicles tend to be lower in joint ventures with Japanese firms, while the marginal costs of horsepower tend to be lower in joint ventures with U.S. firms. These results suggest a possible comparative advantage in horsepower technology among U.S. firms, and a possible comparative advantage in fuel efficiency technology among Japanese firms; which may in turn reflect a possible relative preference for horsepower in the U.S., and a possible relative preference for fuel efficiency in Japan.

We use the model to simulate the effects of counterfactual scenarios regarding state ownership and international joint ventures on equilibrium demand, cost, and welfare. Results suggest that private firms, state-owned firms, the alternative vehicle market, and possibly consumers as well would all benefit if all of the automobile firms in China form international joint ventures with the U.S. or Japan.

The balance of our paper proceeds as follows. We review the literature in Section 2. Section 3 presents our econometric model. We describe the data in Section 4. Section 5 presents our results. Our counterfactual simulations are presented in Section 6. Section 7 discusses our results and concludes.

2. Literature Review

2.1. Structural econometric models of demand and supply in differentiated products markets

The first strand of literature upon which we build is that on structural econometric models of demand and supply in differentiated products markets. Berry (1994) develops techniques for estimating discrete choice demand models which involve "inverting" the market share equation to find the implied mean levels of utility for each good. Models of oligopoly with differentiation on the supply side include Goldberg (1995) and Feenstra and Levinsohn (1995). We build in particular on Berry, Levinsohn and Pakes (1995), who develop techniques for empirically analyzing demand and supply in oligopolistic differentiated products markets using only widely available product-level and aggregate consumer-level data, and then apply these techniques to analyze the equilibrium in the U.S. automobile industry.[4] Pathak and Shi (2021) assess the out-of-sample performance of structural demand models, and find that structural demand models can effectively predict counterfactual outcomes, as long as there are accurate forecasts about auxiliary input variables.

[4] Innovations, extensions, and refinements to Berry, Levinsohn and Pakes (1995) include those made by Petrin (2002); Berry, Levinsohn and Pakes (2004); Hoderlein, Klemela and Mammen (2008); Train and Winston (2007); Dube, Fox and Su (2012); Knittel and Metaxoglou (2014); Reynaert and Verboven (2014); Berry and Haile (2014); Berry and Haile (2016); Bajari et al. (2015); Armstrong (2016); Moon, Shum and Weidner (2018); and D'Haultfoeuille, Durrmeyer and Février (2019). Gandhi and Nevo (2021) survey and discuss empirical models of demand and supply in differentiated products industries with an emphasis on the key ideas arising from the recent applied literature.

2.2. Vehicle markets in China

The second strand of literature we build upon is that on vehicle markets in China. A more detailed review of this literature is provided in Chen, Lin Lawell and Wang (2020).

On the supply side, Hu, Xiao and Zhou (2014) use data on Chinese passenger vehicles to test whether price collusion exists within corporate groups or across groups, and find no evidence for within or cross-group price collusion. Li, Xiao and Liu (2015) estimate a market equilibrium model of the Chinese automobile market with differentiated multiproduct oligopoly, and find evidence for cost reductions through learning by doing and other channels.

On the demand side, Sun et al. (forthcoming) analyze the effects of a nationwide consumer boycott of Japanese brands in China in 2012 on sales of automobile brands from different countries-of-origin. Barwick, Cao and Li (2021) document the presence of local protectionism in China's automobile market and show that local protectionism leads to significant consumer welfare loss arising from choice distortions. Dai, Gong and Tan (forthcoming) find that, despite a consistently stronger preference and cost advantages for local manufacturers in the Chinese automobile industry, the extent of home bias is limited by a more elastic demand for home brands on average.

In terms of vehicle-related policies, Xiao and Ju (2014) explore the effects of consumption-tax and fuel-tax adjustments in the Chinese automobile industry. Xiao, Zhou and Hu (2017) present a welfare analysis of the vehicle quota system of Shanghai, China. Li (2018) empirically quantifies the welfare consequences of two mechanisms for distributing limited vehicle licenses as a measure to combat worsening traffic congestion and air pollution. Chen, Hu and Knittel (2021) analyze China’s subsidy program for fuel efficient vehicles. Yang et al. (2020) analyze the effect of Beijing’s vehicle ownership restrictions on travel behavior. Bai et al. (2020) analyze the impact of the requirement for foreign automakers to set up joint ventures with domestic automakers in return for market access on facilitating knowledge spillover and quality upgrading, and demonstrate the presence of knowledge spillover from joint ventures to their affiliated automakers as well as to non-affiliated automakers located in the same city.

2.3. Mixed oligopoly and state-owned firms

The third strand of literature we upon which we build is that on mixed oligopoly. A mixed oligopoly is defined as an oligopolistic market structure with a relatively small number of firms for which the objective of at least one firm differs from that of other firms (De Fraja and Delbono, 1990), as opposed to a private oligopoly in which all firms have the objective of profit maximization. Usually in a mixed oligopoly there is a public firm competing with a multitude of profit-maximizing firms (Poyago-Theotoky, 2001).

Much of the literature on mixed oligopoly to date has been theoretical (De Fraja and Delbona, 1989; Fjell and Pal, 1996; White, 1996; Poyago-Theotoky, 2001; De Fraja, 2009; Bennett and La Manna, 2012; Lutz and Pezzino, 2014; Haraguchi and Matsumura, 2016). We build on this theoretical literature by empirically modeling the Chinese automobile market as a mixed oligopoly, and by allowing the objectives of state-owned firms to differ from those of private firms.

A related literature is that on the objectives of state-owned firms. This literature includes analyses of state-owned firms in other countries in other industries such as the petroleum industry (Ghandi and Lin, 2012; Kheiravar, Lin Lawell and Jaffe, 2021). Berkowitz, Ma and Nishioka (2017) find that the productivity of China's state-owned enterprises lagged that of foreign and private firms, and that China's state-owned enterprises became more profitable following the enactment of reforms in the mid-1990s because they had access to cheap capital and not because they were productive (Berkowitz, Ma and Nishioka, 2017). Harrison et al. (2019) show that state-owned enterprises in China that were privatized continue to benefit from government support relative to private enterprises; compared to private firms that were never state-owned, privatized state-owned enterprises are favored by low interest loans and government subsidies. Abolhassani, Wang and de Haan (2019) find that government control of firms in China, measured by the shareholdings that are directly and indirectly controlled by the government, is negatively related with firms' financial performance. Chen, Igami, Sawada, and Xiao (2021) find that private firms in China are more productive than state-owned enterprises on average, but the benefits of privatization take several years to fully materialize.

3. Econometric Model

3.1. Demand

On the demand side, we use a random coefficients model of vehicle demand (Berry, Levinsohn and Pakes, 1995). A random coefficients model addresses the independence of irrelevant alternatives problem in traditional logit models (McFadden, 1973; McFadden, 1974) by allowing for interactions between unobserved consumer characteristics and observed product characteristics, thus allowing different consumers to vary in how much they like different car characteristics, and thereby generating reasonable substitution patterns.

Let's suppose that there are J vehicle models j available in the vehicle market. Let $x_j = \{x_{jk}\}$ denote a vector of observable vehicle characteristics k for vehicle model $j \in \{1,...,J\}$, ξ_j denote a vector of unobservable vehicle characteristics for vehicle model j, p_j denote the price of vehicle model j, β_k denote the mean taste parameter for vehicle characteristic k, ζ_{ik} denote a characteristic of consumer i that affects *i's* taste for vehicle characteristic k, and y_i denote consumer i's income. The random coefficients specification for the utility of consumer i for vehicle model j is given by:

$$u_{ij} = \delta_j + \nu_{ij} \ , \tag{1}$$

where δ_j is the common component of the utility for vehicle model j and is given by:

$$\delta_j = x_j\beta - \alpha p_j + \xi_j \ , \tag{2}$$

and where the first two terms in the idiosyncratic component ν_{ij} interact consumer and product characteristics:

$$\nu_{ij} = \sum_k x_{jk}\sigma_k\zeta_{ik} - \frac{1}{y_i} p_j + \varepsilon_{ij} \ , \tag{3}$$

where ε_{ij} is distributed type I extreme value. Plugging in equation (2) for the common component of the utility δ_j and equation (3) for the idiosyncratic component ν_{ij} in the utility function in equation (1), we obtain the following expression for the utility of consumer i for vehicle model j:

$$u_{ij} = x_j\beta + \xi_j + \sum_k x_{jk}\sigma_k\zeta_{ik} - \alpha p_j - \frac{1}{y_i} p_j + \varepsilon_{ij} \ . \tag{4}$$

Owing to the idiosyncratic component ν_{ij} that interacts consumer and product characteristics, our model allows consumers to vary in their preferences for various car characteristics and for price. We assume that the unobservable consumer characteristics ζ_{ik} that may affect consumer i's preferences for characteristic k have a standard normal distribution so that the mean and variance of the marginal utilities associated with characteristic k across all consumers are β_k and $\sigma_k{}^2$, respectively.[5] Our model similarly allows consumers to vary in their disutility for price: consumer marginal disutility for price has a common component α as well as an idiosyncratic component that varies inversely with consumer *i*'s income y_i. We assume income y_i is log normally distributed, and calibrate its mean and standard deviation empirically from income data.[6]

We normalize the utility for the outside option $j = 0$ of not purchasing a vehicle to be:

$$u_{i0} = \xi_0 + \sigma_0 \zeta_{i0} + \varepsilon_{i0} \ , \tag{5}$$

where ε_{i0} is distributed type I extreme value.[7] If consumer *i* chooses the outside option of not purchasing a new vehicle, this may mean that they opt to use other forms of transportation, such as public transportation, subways, or buses; that they continue to use a car they already own; or that they purchase a used car.

The share s_j of consumers who purchase vehicle model *j* is therefore given by:

$$s_j = E\left[\frac{\exp\left(\delta_j + \sum_k x_{jk} \sigma_k \zeta_{ik} - \frac{1}{y_i} p_j \right)}{1 + \sum_{j'=1}^{J} \exp\left(\delta_{j'} + \sum_k x_{j'k} \sigma_k \zeta_{ik} - \frac{1}{y_i} p_{j'} \right)} \right] \ , \tag{6}$$

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[5] Examples of unobservable consumer characteristics that may affect consumer preferences for car characteristics include age, education, gender, family size, occupation, commute distance, risk aversion, preferences for environmental conservation, whether a consumer likes fast cars, whether a consumer likes safe cars, whether a consumer likes large cars, whether a consumer lives in a rural or urban area, whether a consumer drives to remote outdoor areas (where a rugged truck/SUV might be preferred), local protectionism, local car dealers, local promotions, what types of cars their neighbors purchase, whether the vehicle is intended for private household use or instead for public or business use, and anything else that may affect how much different consumers like different car characteristics.

[6] The marginal disutility of price is $\alpha + \alpha_y \frac{1}{y_i}$, with mean $E\left[\alpha + \alpha_y \frac{1}{y_i} \right] = \alpha + \alpha_y E\left[\frac{1}{y_i} \right]$. If income y_i is log normally distributed with mean μ_y and standard deviation σ_y, then the mean marginal disutility of price is $\alpha + \alpha_y e^{-\mu_y + 0.5\sigma_y^2}$. Calibrating the mean μ_y and standard deviation σ_y empirically from data on annual urban per capita income (in Yuan) across all provinces from the China Statistical Year Book, and averaging over all years, we get $\mu_y = 9.9712$ and $\sigma_y = 0.1866$, which yields a mean marginal disutility of price of $\alpha + 0.00004754707\alpha_y$. Thus, as discussed and verified in Section 5.4, as long as the magnitude of α_y is not very large, the mean marginal disutility of price is not affected much by α_y.

[7] Since market shares depend only on differences in utilities, the actual estimation algorithm ends up estimating a model where the deterministic utility for the outside option $j = 0$ is "normalized" to zero. Given equation (5), this implies that there is a random coefficient on the constant term in the utility function for the inside goods $j \in \{1,...,J\}$ (Berry, Levinsohn and Pakes, 1995).

where the expectation is taken over the distribution of the individual characteristics ζ_{ik} and income y_i. To calculate this expectation numerically, we take random draws from the distribution of the individual characteristics ζ_{ik} and income y_i.

In a random coefficients demand model, owing to the interactions between consumer preferences and product characteristics in v_{ij}, consumers who have a preference for size will tend to attach a high utility to all large cars, and this will induce a larger, more realistic cross-price elasticity between large cars. Thus, unlike traditional logit models that do not allow for interactions between unobserved consumer characteristics and observed product characteristics, our random coefficients model of vehicle demand generates reasonable substitution patterns.

We calculate the common component of utility δ_j by deriving the inverse market share function $\delta_j(s_j)$, where s_j is the share of consumers who purchase vehicle model *j*. To derive the inverse market share function $\delta_j(s_j)$, we first compute the expected market share function (6) as a function of the common components of utility δ_j, where the expectation is taken over the distribution of consumer characteristics and income, and then invert the expected market share function (6) to derive the common component of utility δ_j as a function of market share s_j via a contracting mapping algorithm. Following Li (2018), we employ Newton's method to increase the speed of convergence.

The estimation equation on the demand side, which is obtained by substituting the common component of utility δ_j in equation (2) with the inverse market share function $\delta_j(s_j)$ derived above, is given by:

$$\delta_j(s_j) = x_j\beta - \alpha p_j + \xi_j \ . \tag{7}$$

Identification of the demand parameters comes from the data on vehicle market shares, prices, and characteristics; and from our instruments that generate exogenous variation in choice sets, including changing prices (Berry and Haile, 2014). The mean marginal utility parameters β are identified by correlations between market shares and observable product characteristics (Miravete, Moral and Thurke, 2018). Similarly, the parameter α in the marginal disutility of price is identified by correlations between market shares and price. The distribution of random coefficients is nonparametrically identified by local variation in product characteristics, our linear random coefficients specification, our assumption that product characteristics x_j enter demand linearly (and not as higher-order terms or interactions), and our assumption that ε_{ij} is distributed type I extreme value (Fox et al., 2012; Dunker, Hoderlein, and Kaido, 2017). We use variation in product characteristics, prices, and quantities to isolate substitution patterns and identify the marginal utility standard deviation parameters σ which govern product substitution patterns among observable characteristics (Miravete, Moral and Thurke, 2018).

3.2. Supply

On the supply side, we innovate upon the literature by allowing state-owned automobile companies to have different objectives from private automobile companies. We assume a Bertrand (Nash-in-prices) mixed oligopolistic equilibrium among multiproduct firms.

We assume that each private firm *f* maximizes the joint profits π_f over all vehicle models $j \in J_f$ that the firm produces:

$$\pi_f = \sum_{j \in J_f} \left(p_j - c_j \right) M s_j \quad , \tag{8}$$

where M is the total number of consumers and c_j is the marginal cost for vehicle *j*.

The estimation equation on the supply side for private firms is given by the following pricing equation:

$$p - \Delta^{-1} s = c \, , \tag{9}$$

where *p* is a vector of vehicle prices, one for each vehicle *j*; Δ is a matrix in which $\Delta_{jk} = -\frac{\partial s_k}{\partial p_j}$ if vehicle models *j* and *k* are produced by the same firm and $\Delta_{jk} = 0$ otherwise; *s* is a vector of vehicle market shares, one for each vehicle *j*; and *c* is a vector of vehicle marginal costs, one for each vehicle *j*.

Unlike private firms, state-owned firms may have objectives other than profit maximization alone. We allow for the possibility that state-owned firms may care about objectives other than profit, and allow the data to tell us whether and how much state-owned firms care about these other objectives. In particular, we specify the utility function of state-owned firms as a weighted sum of several possible objectives, the weights for which we estimate econometrically.

These objectives include profits π_f, consumer surplus CS, and alternative vehicle production ALT_f. The utility U_f of a state-owned firm *f* is therefore given by:

$$U_f = \rho_1 \pi_f + \rho_2 CS + \left(1 - \rho_1 - \rho_2\right) ALT_f \ . \tag{10}$$

As before, profits π_f are the joint profits over all vehicle models $j \in J_f$ that the state-owned firm *f* produces, as given by equation (8).

Consumer surplus CS is the sum over the utilities of all the consumers in the market in that year, assuming each consumer chooses the one good *j* (which may be the outside option of not buying a car) that maximizes his/her utility:

$$\begin{aligned} CS &= \sum_i \max_j u_{ij} \\ &= M \cdot E_{y_i}\left[E_\varepsilon[\max_j u_{ij}] \right] \\ &= M \cdot E_{y_i}\left[\ln\left(\sum_{j=1}^{J} \exp\left(\delta_j + \sum_k x_{jk}\sigma_k \zeta_{ik} - \frac{1}{y_i} p_j \right) + 1 \right) \right] \ , \end{aligned} \tag{11}$$

where the expectation is taken over the distribution of income y_i. We include consumer surplus among the possible objectives of state-owned firms following the previous literature that has modeled the objectives of state-owned enterprises as a weighted sum of profits and consumer surplus (e.g., Peltzman, 1971; Timmins, 2002; Hochman and Zilberman, 2015; Kheiravar, Lin Lawell and Jaffe, 2021; Sears, Lin Lawell and Walter, 2021). Since each state-owned firm is at least partially controlled by the government, since the government may potentially consider the utilities of all consumers, we allow for the possibility that state-owned firms care about the utilities of all the consumers in the market in that year.[8] By choosing the prices of the vehicle models it produces, each state-owned firm not only directly affects the prices of their own vehicle models, but, since each firm is best responding to every other firm in the Bertrand (Nash-in-prices) mixed

[8] It is possible that the Chinese central government may care about the utilities of all consumers in China. Thus, it is possible that state-owned firms that are at least partially owned by the central government may care about the utilities of all consumers. In addition, the central government controls the appointment, evaluation, promotion, and demotion of subnational officials in China, and the career paths of these officials are determined by the performance of their jurisdictions (Xu, 2011). The central government directly controls the key positions at the province level and grants the provincial government the power to appoint key officials at the prefecture level (Suárez Serrato, Wang and Zhang, 2019). Thus, state-owned firms that are at least partially owned by local governments in China are at least partially controlled by the Chinese central government as well. Thus, state-owned firms, whether partially owned by the central or local governments, are all at least partially controlled by partially the central government, and therefore may care about the utilities of all consumers.

oligopolistic equilibrium, each state-owned firm also indirectly affects the prices of the vehicle models produced by other state-owned and private firms. We therefore allow for the possibility that state-owned firms may care about consumer surplus; whether they actually do is an empirical question that our econometric estimation enables us to examine.

We define alternative vehicles as vehicles that are powered by alternative fuel sources other than gasoline or diesel. These alternative vehicles include hybrid cars powered on both gasoline and electricity, purely electric cars, plug-in hybrid cars, and extended range electric vehicles. The alternative vehicle production objective ALT_f is given by the following quadratic function of the number of alternative vehicles $Q_{f,alt}$ produced by state-owned firm *f*:

$$ALT_f = \lambda_1 \left(Q_{f,alt} - \lambda_2 \right)^2 + \left(1 - \lambda_1 \right) Q_{f,alt} \ , \tag{12}$$

where the number of alternative vehicles $Q_{f,alt}$ produced by firm *f* is given by:

$$Q_{f,alt} = \sum_{j \in J_f ; j \in alt} q_j = \sum_{j \in J_f ; j \in alt} M s_j \ . \tag{13}$$

The alternative vehicle production objective ALT_f is a weighted sum of the number of alternative vehicles $Q_{f,alt}$ produced by state-owned firm *f*, and a quadratic term measuring the square of the difference between the number of alternative vehicles $Q_{f,alt}$ produced by state-owned firm *f* and some constant λ_2. If the weight λ_1 the state-owned firm places on the quadratic term is 0, then the alternative vehicle production objective ALT_f is simply the number of alternative vehicles $Q_{f,alt}$ produced by state-owned firm *f*. The weight λ_1 the state-owned firm places on the quadratic term and the constant λ_2 in the quadratic term are among the parameters we estimate.

We include alternative vehicle production among the possible objectives of state-owned firms since alternative vehicle production appears to be an objective the Chinese government cares about and has prioritized for some time. For example, in 2009 the central government issued documents calling for an ambitious production target of 500,000 electric vehicles by 2011 (Howell, Lee and Heal, 2015). China's twelfth Five-Year Plan (2011-2015) – its core economic and social development roadmap – identified the alternative fuel vehicle industry as one of seven strategic emerging industries to which the country would devote enhanced policy and financial support (Marquis, Zhang and Zhou, 2013). In addition, as China more recently revealed when it announced its "Made in China 2025" strategic plan in 2015, alternative vehicles are among the 10 areas where the country plans to take the lead worldwide (Tse and Wu, 2018). As explained in more detail when we describe and summarize our data in Section 4, alternative vehicles are only produced by state-owned firms during the time period of our analysis.

China has implemented policies to promote fuel efficiency. As we explain in more detail below, we include terms in the marginal cost of all firms, both private and state-owned, to measure the effects of China's fuel efficiency policies. By including alternative vehicle production among the possible objectives of state-owned firms, we allow for the possibility that state-owned firms may potentially care more about alternative vehicle production even beyond the effects of China's fuel efficiency policies that are common to all firms. Whether state-owned firms actually do is an empirical question that our econometric estimation enables us to examine.

We do not make any assumptions about whether or how much the state-owned firms care about objectives other than profit, but instead allow the data to tell us whether and how much state-owned firms care about these other objectives. Thus, the weights $\rho = (\rho_1, \rho_2)$ on each of the possible objectives in the state-owned company's utility function in equation (10) are among the parameters we estimate.

Identification of the cost parameters comes from the data on vehicle market shares, prices, and characteristics, including the vehicle market shares, prices, and characteristics of private firms which care solely about profit; and from our instruments. Of the 56 firms in our data set, 12 of them are private firms. The identification of the cost parameters follows from variation in observable product characteristics and implied marginal costs, where the latter depends on variation in price and market shares (Miravete, Moral and Thurke, 2018).

Identification of the weights $\rho = (\rho_1, \rho_2)$ that a state-owned firm puts on each of the possible objectives in the state-owned company's utility function in equation (10) and of the parameters $\lambda = (\lambda_1, \lambda_2)$ in the alternative vehicle production objective of state-owned firms comes from variation in state ownership among firms, and from variation in alternative vehicle production among state-owned firms. Identification of the weights $\rho = (\rho_1, \rho_2)$ a state-owned firm puts on profits versus other objectives such as consumer surplus and alternative vehicle production comes from variation across firms in whether a firm is private or state-owned. Of the 56 firms in our data set, 12 are private and 44 are state-owned. Identification of the parameters $\lambda = (\lambda_1, \lambda_2)$ in the alternative vehicle production objective of state-owned firms comes from variation in alternative vehicle production among state-owned firms. The number of alternative vehicles produced in a firm-year across the 44 state-owned firms in our data set ranges from 0 to 7,302 alternative vehicles.

The pricing equation for the state-owned firms is given by:

$$p-(\Delta)^{-1}\left[s-\frac{\rho_2}{\rho_1}e+\frac{1}{\rho_1}\left(\left(1-\rho_1-\rho_2\right)\left(1+\lambda_1(2M\sum_l s_l-2\lambda_2-1)\right)\right)\Delta^l\cdot 1_J\right]=c \ , \tag{14}$$

where Δ^l is a matrix in which $\Delta^l_{jl}=\frac{\partial s_l}{\partial p_j}$ if vehicle model l is an alternative vehicle and vehicle models j and l are produced by the same firm, and $\Delta^l_{jl}=0$ otherwise; e is a vector whose j^{th} element is given by:

$$E_{y_i}=\left[\frac{exp\left(\delta_j+\sum_k x_{jk}\sigma_k\zeta_{ik}-\frac{1}{y_i}p_j\right)\left(\alpha-\frac{1}{y_i}\right)}{\sum_{j'}\left[exp\left(\delta_{j'}+\sum_k x_{j'k}\sigma_k\zeta_{ik}-\frac{1}{y_i}p_{j'}\right)\right]+1}\right]; \tag{15}$$

1_J is a J x1 vector of ones; and where, as before, p is a vector of vehicle prices, one for each vehicle j; Δ is a matrix in which $\Delta_{jk}=-\frac{\partial s_k}{\partial p_j}$ if vehicle models j and k are produced by the same firm and $\Delta_{jk}=0$ otherwise; s is the vector of vehicle market shares, one for each vehicle j; and c is the vector of vehicle marginal costs, one for each vehicle j.

The estimation equation on the supply side for both private and state-owned firms is our specification for the marginal cost c_j for each car j:

$$c_j=x_j\gamma+w\Gamma+\eta q_j+tech_{int}\cdot\psi_1+techIJVC_{int}\cdot\psi_2+fuel_{int}\cdot\psi_3+\omega_j \ , \tag{16}$$

where the marginal cost c_j is given by the pricing equation (9) for private firms and the pricing equation (14) for state-owned firms; $x_j=\{x_{jk}\}$ is a vector of observable vehicle characteristics k for vehicle model $j\in\{1,...,J\}$, as before; w are dummies for each international joint venture company g; $tech_{int}$ are terms interacting the international joint venture dummy with technology-related vehicle characteristics; $techIJVC_{int}$ are terms interacting the international joint venture country dummies with technology-related vehicle characteristics; $fuel_{int}$ are fuel efficiency policy interaction terms; and ω_j are unobservable cost variables.

To examine whether joint ventures between Chinese automobile companies and different international car companies have different marginal costs c_j, we include dummies w for joint ventures with each international car company in our specification of marginal costs c_j. In particular, for each international car company g with which at least one Chinese automobile company has formed a joint venture, we include a dummy variable for whether the firm f producing car j is a joint venture between a Chinese automobile company and international car company g.

To examine whether Chinese automobile companies that form joint ventures with international car companies have better technology, our specification for marginal cost c_j includes interactions $tech_{int}$ between the international joint venture dummy with some of the technology-related car characteristics. The international joint venture dummy equals 1 if the firm is a joint venture between a Chinese automobile company and an international car company, and 0 otherwise. The technology-related car characteristics we use are: whether the car is an alternative vehicle, fuel efficiency, and horsepower.

Furthermore, to examine whether Chinese automobile companies that form joint ventures with international car companies from a particular country have better technology, our specification for marginal cost c_j also includes interactions $techIJVC_{int}$ between an international joint venture country dummy and technology-related vehicle characteristics. The international joint venture country dummy is equal to 1 if the firm is a joint venture between a Chinese car company and an international car company headquartered in a particular country, and 0 otherwise. During the time period of our data set, Chinese car companies formed international joint ventures with international car companies from six countries: Japan, Germany, Britain, U.S., South Korea, Sweden, France, and Italy.

China's automobile policies include (1) a fuel economy standard that applies to individual vehicle models; and (2) a Corporate Average Fuel Consumption (CAFC) standard that applies to an automobile firm's sales-weighted average fuel consumption (Chen, Lin Lawell and Wang, 2020). There were no fiscal penalties on noncompliant carmakers under the standards during the observed time period in this paper, and the implementation and enforcement aspects of the standard were not released until 2014, after the observed time period in this paper (He and Yang, 2014). Since the standards were not binding and noncompliance occurs frequently in the observed data, we do not impose these policies as constraints on firms, but instead measure any costs firms may have incurred from violating the respective standards. Although firms did not incur any direct explicit financial penalties from violating the standards (He and Yang, 2014), it is possible that firms that did not comply with the standards may have faced other perceived, indirect, and/or implicit costs; such costs may include, for example, administrative costs or possible indirect costs from government disapproval. It is also possible that firms that over-complied with the standards (by having a better fuel economy than was required) may have received some benefits -- whether perceived, indirect, implicit, or otherwise -- from doing so; such benefits may include, for example, the possibility of subsidies, preferential taxes, discount loans, or other benefits from the government (Yu et al., 2019). Thus, to measure the effects of China's fuel economy standard and Corporate Average Fuel Consumption (CAFC) standard, we include three fuel efficiency policy interaction terms $fuel_{int}$ in the marginal cost c_j.

The first fuel efficiency policy interaction term is the fuel economy standard minus fuel efficiency, which measures if a firm incurs costs if it produces a car with worse fuel economy than the fuel economy standard. A positive coefficient on the fuel economy standard minus fuel efficiency would mean that a firm incurs costs if it produces a car with worse fuel economy than the fuel economy standard, and also that a firm benefits if it produces a car with better fuel economy than the fuel economy standard.

The second fuel efficiency policy interaction term is a dummy variable for the CAFC policy being in effect. Since the CAFC went into effect in 2012 (Chen, Lin Lawell and Wang, 2020), this CAFC policy dummy is equal to 1 for the years 2012 onwards, and is 0 before 2012. Although the CAFC was not binding during the 2010-2013 period of our data set (Chen, Lin Lawell and Wang, 2020), by including this term we allow for the possibility that the presence of the CAFC may affect marginal costs. The CAFC policy dummy measures if firms face higher marginal costs when the CAFC policy is in effect. A positive coefficient on the CAFC policy dummy would mean that firms face higher marginal costs when the CAFC policy is in effect, possibly in part from the compliance costs of having to average the fuel efficiency over all their cars to meet the CAFC standard.

The third fuel efficiency policy interaction term is the CAFC policy dummy interacted with the difference between the CAFC target and fuel efficiency, and measures if a firm incurs costs from producing a car with worse fuel economy than the CAFC target when the CAFC is in place. Even though the CAFC was not binding during the period of our data set, by including this term we allow for the possibility that the presence of the CAFC may adversely affect a firm if it produces a car with worse fuel economy than the CAFC target. For example, if a firm produces a car with worse fuel economy than the CAFC target, then it becomes harder for the firm to meet the CAFC, and this term may capture, for example, the resulting increase in possibility that the firm may incur some fine, penalty, or cost if it does not meet the CAFC. A positive coefficient on the CAFC policy dummy interacted with the difference between the CAFC target and fuel efficiency would mean that a firm incurs costs from producing a car with worse fuel economy than the CAFC target when the CAFC is in place, perhaps because by doing so it then becomes harder for the firm to meet the CAFC.

3.3. Estimation

The parameters to be estimated include parameters in consumer demand, parameters in firm costs, and parameters in the utility function of state-owned firms. The consumer demand parameters include the means β and standard deviations σ of the marginal utility associated with each vehicle characteristic, and the parameter α in the marginal disutility of price. The parameters in firms' marginal cost include the coefficients γ on vehicle characteristics, the coefficients Γ on the dummies for each international joint venture company *g*, the coefficient η on quantity, the coefficients ψ_1 on the terms interacting the international joint venture dummy with technology-related vehicle characteristics, the coefficients ψ_2 on terms interacting the international joint venture country dummies with technology-related vehicle characteristics, and the coefficients ψ_3 on fuel efficiency policy interaction terms. The parameters in the utility function of state-owned firms include the weights ρ on the different objectives in a state-owned firm's utility function, and the parameters λ in the alternative vehicle production objective of state-owned firms.

Because the observed equilibrium prices and quantities are simultaneously determined in the supply-and-demand system, instrumental variables are needed to address the endogeneity problem (Goldberger, 1991; Manski, 1995; Angrist et al., 2000; Lin, 2011). Since price and the market share variables are endogenous in demand and supply, we use instruments for the endogenous price and market share variables. In addition, observable vehicle characteristics x may also be correlated with either the demand-side unobservable ξ or the cost-side unobservable ω, and therefore may be endogenous as well. For example, observable vehicle characteristics such as horsepower may be correlated with unobservable cost variables such as a quality index, both of which might be more costly to produce (Berry, Levinsohn and Pakes, 1995). Thus, we also instrument for the vehicle characteristics as well.

The instrumental variables we use in our estimation build on the work of Berry, Levinsohn and Pakes (1995). We construct two different types of instrumental variables based on each car characteristic. Both types of instrumental variables measure the exogenous degree of differentiation of each product in the market, and therefore circumvent the weak identification problem in demand models with flexible substitution patterns (Gandhi and Houde, 2020).

The first instrumental variable we create for each characteristic r is the number of cars that have a similar value of attribute r to car j. Two cars j and k are "similar" in characteristic r if the squared difference in their values of that characteristic is less than or equal to one tenth of the squared difference between the maximum and minimum values of that characteristic among all cars: $(x_{jr} - x_{kr})^2 \leq \frac{1}{10}\left(\max(x_r) - \min(x_r)\right)^2$. For the car capacity in terms of number of seats, we use a cutoff value of 2 instead of $\frac{1}{10}\left(\max(x_r) - \min(x_r)\right)^2$. A second instrumental variable we create for each characteristic r is the value of characteristic r for the car k closest to car j in the value of the characteristic.

The number of cars with similar values of the characteristic, and the value of the characteristic for the car k closest to car j in the value of the characteristic are good instruments for price in the demand equation because characteristics of other cars k are independent of the utility for a particular car j, and because they are correlated with price via the markup in the supply-side first-order conditions. Characteristics of other cars k also serve as good instruments for the market share of car j in the supply-side pricing equation.

We compute the demand-side unobservable ξ as the residual in the common component of the demand-side utility estimation equation (7). We compute the cost-side unobservable ω as the residual in the supply-side marginal cost estimation equation (16), where the marginal cost is given by the pricing equation (9) for private firms and the pricing equation (14) for state-owned firms. We then interact the instruments with the computed demand- and cost-side unobservables to form the moment conditions.

The demand and supply side equations are jointly estimated using instruments for the endogenous price and market share variables via generalized method of moments (GMM). One challenge is determining whether the model has converged at a global or local minimum (Knittel and Metaxoglou, 2014). We experimented with several combinations of starting values to initialize the parameters to be estimated in order to find the set of parameters that minimized the weighted sum of squared moments.

Standard errors are formed by a nonparametric bootstrap. Model-displacement-style-years are randomly drawn from the data set with replacement to generate 100 independent pseudo-samples of size equal to the actual sample size. The structural econometric model is run on each of the new pseudo-samples. The standard error is then formed by taking the standard deviation of the estimates from each of the random samples.

As explained above, identification of the demand parameters comes from the data on vehicle market shares, prices, and characteristics; and from our instruments that generate exogenous variation in choice sets, including changing prices (Berry and Haile, 2014). The mean marginal utility parameters β are identified by correlations between market shares and observable product characteristics (Miravete, Moral and Thurke, 2018). Similarly, the parameter α in the marginal disutility of price is identified by correlations between market shares and price. The distribution of random coefficients is nonparametrically identified by local variation in product characteristics, our linear random coefficients specification, our assumption that product characteristics x_j enter demand linearly (and not as higher-order terms or interactions), and our assumption that ε_{ij} is distributed type I extreme value (Fox et al., 2012; Dunker, Hoderlein, and Kaido, 2017). We use variation in product characteristics, prices, and quantities to isolate substitution patterns and identify the marginal utility standard deviation parameters σ which govern product substitution patterns among observable characteristics (Miravete, Moral and Thurke, 2018).

Also as explained in more detail above, identification of the cost parameters comes from the data on vehicle market shares, prices, and characteristics, including the vehicle market shares, prices, and characteristics of private firms which care solely about profit; and from our instruments. The identification of the cost parameters follows from variation in observable product characteristics and implied marginal costs, where the latter depends on variation in price and market shares (Miravete, Moral and Thurke, 2018). Identification of the weights $\rho = (\rho_1, \rho_2)$ that a state-owned firm puts on each of the possible objectives in the state-owned company's utility function in equation (10) and of the parameters $\lambda = (\lambda_1, \lambda_2)$ in the alternative vehicle production objective of state-owned firms comes from variation in state ownership among firms, and from variation in alternative vehicle production among state-owned firms.

4. Data

We apply our model to a comprehensive annual data set on the sales, prices, and characteristics of the majority of vehicle makes and models marketed in the Chinese automobile industry over the years 2010 to 2013. Our data set consists of 2,215 vehicle models over the years 2010 to 2013.

We delineate vehicle models as follows. First, we treat each year as a separate market, each with a different set of J vehicle models to choose from, and therefore treat vehicle models from different years as different vehicle models that may differ in their price and characteristics. Second, since some models have different engine displacements, we further delineate vehicles by "model displacement", which we define as a combination of a model with a specific engine displacement. For example, the Toyota Camry model comes in engine displacements of 1.6L and 1.8L, which we categorize as two different model displacements. For each model, we have collected information on price and quantity sales for each engine displacement of that model. Third, for each model displacement, we have also collected information on vehicle characteristics for each style within that model. We treat each style of a model-displacement-year as a single vehicle model observation as long as it differs from other styles within that model in any of the vehicle characteristics we examine.

The quantity sales data for each model displacement is collected from the China Auto Market Almanac. We have collected two sets of price data, both in units of 10,000 RMB. We obtained data on prices for each model displacement from the *China Automotive Industry Yearbook*. Since there are different styles for each model displacement, we also obtained data on prices for each style of each model displacement from *www.autohome.com.cn*, which is one of the largest vehicle websites in China.[9] We confirm that prices from the two data sets are comparable. The price data we collect is the nominal manufacturer's suggested retail price (MSRP); transactions prices are unfortunately not available. We obtain information about vehicle characteristics from *www.autohome.com.cn.*

Unlike in the U.S. and France,[10] China's automobile market has infrequent promotions from manufacturers or dealers, and retail prices are often very close to or the same as MSRPs (Li, Xiao and Liu, 2015; Barwick, Cao and Li, 2021). Promotions are mostly concentrated among low-end vehicle models (Hu, Xiao and Zhou, 2014; Li, Xiao and Liu, 2015). For high-end models, transaction prices could be even higher than MSRPs (Li, Xiao and Liu, 2015). Consumers of high-end models are usually less sensitive to the price. In addition, luxury good purchases that are socially observable could be driven by concerns of status seeking and conspicuous consumption that are well documented among Chinese consumers (Brown, Bulte and Zhang, 2011). Given the unavailability of transaction price data, and given that any potential bias on the estimates of price elasticities in China may not be as severe as suggested by those studies on auto markets in the U.S. and France, we follow the automobile demand literature, including the literature on the Chinese automobile market (Deng and Ma, 2010; Hu, Xiao and Zhou, 2014; Li, Xiao and Liu, 2015; Barwick, Cao and Li, 2021), and use MSRPs in our analysis.

We delineate firms as follows. If the name of the car manufacturers are different in *www.autohome.com.cn*, we treat the manufacturers as different Chinese automobile companies. Since each international joint venture is at least partially controlled by the international car company involved in the joint venture (Hu, Xiao and Zhou, 2014), if a Chinese automobile company forms joint ventures with different international car companies, each international joint venture that the Chinese automobile company forms with a different international car company is considered a different firm. There are 56 firms in our sample, of which 43 involved a joint venture with an international car company for at least one year over the 2010-2013 period of our data set.

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[9] Other famous and widely used car websites include: *http://auto.sohu.com*, *http://auto.163.com*, *http://auto.sina.com.cn*, *http://auto.qq.com*

[10] In the context of U.S. auto market, Busse, Silva-Risso and Zettelmeyer (2006) suggest that the actual transaction price could be quite different from MSRP due to dealer and consumer promotions; Hellerstein and Villas-Boas (2010) show that the median transaction prices could be several thousand dollars less than the MSRP and exhibit more monthly variation than the MSRP; and Langer and Miller (2012) document that automakers use cash incentives to offset changes in fuel expenses due to gasoline price fluctuations and suggest that consumer demand for fuel economy could be underestimated if manufacturer discounting is ignored. In the case of the French automobile market, D'Haultfoeuille, Durrmeyer and Février (2019) find that discounting arising from price discrimination is significant.

One notable feature of the Chinese automobile industry is that some of the Chinese automobile companies are state-owned. We obtain information about the ownership of the car companies from *baike.baidu.com* and from China Industry Business Performance Data. Since the majority of car companies in China are operated under shareholding system, there are few car companies that are 100% state-owned. Nevertheless, governments do hold a majority of the stocks of some of the companies. Throughout the paper, a stated-owned firm is defined as a car manufacturer for which a majority of the stock of its parent company (i.e., more than 50%) is held by either the central or local Chinese government. Of the 56 firms in our sample, 44 of them are state-owned.

There are 6 vehicle models (i.e., 6 model-displacement-style-year observations) in our data set that are powered by alternative fuel sources other than gasoline or diesel. These alternative vehicles include hybrid cars powered on both gasoline and electricity, purely electric cars, plug-in hybrid cars, and extended range electric vehicles. The number of alternative vehicles sold by a firm in a year for firm-years with alternative vehicle sales ranged from 350 to 7,302 alternative vehicles.

Table 1a presents summary statistics for price, quantity, and the vehicle characteristics we have chosen to focus on in our structural econometric model: fuel efficiency, length, weight, passenger capacity (in terms of the number of seats), and horsepower. Unlike in the U.S., where the measurement of fuel efficiency is mileage per gallon, China uses a fuel consumption measurement of liters per 100 kilometers (the smaller the value is, the better in terms of energy efficiency). Our fuel efficiency variable is therefore the reciprocal of the fuel consumption measurement, and is in units of 100 kilometers per liter of gasoline.

Tables 1b and 1c present summary statistics for vehicle models produced by state-owned firms and private firms, respectively. While the summary statistics are similar for most vehicle characteristics, there are a few notable differences between vehicle models produced by state-owned firms and private firms. First, the average vehicle model price is higher for state-owned firms compared to private firms. Second, the range in prices among vehicle models produced by state-owned firms is greater than that for vehicle models produced by private firms: the minimum price is lower and the maximum price is higher for state-owned firms. Third, the quantity of vehicles sold per vehicle model is higher on average for vehicle models produced by state-owned firms. Fourth, alternative vehicles are only produced by state-owned firms. These differences in price, quantity, and alternative vehicle production suggest that it may be possible that state-owned firms may have different objectives from private firms. For example, the state-owned firms' lower minimum price and higher average quantity of vehicles sold per vehicle model may be a result of state-owned firms putting some weight on consumer surplus in their utility function. Likewise, the state-owned firms' non-zero alternative vehicle production, higher maximum price, and higher (non-sales-weighted) average vehicle model price may be a result of state-owned firms putting some weight on alternative vehicle production in their utility function, and therefore including higher-cost and higher-priced alternative vehicles in their portfolio.

We use annual data on the adult population (ages 15-64) from World Development Indicators to proxy for the automobile market size. The total quantity sales for year over 2010-2013 was approximately 28.8 million vehicles per year; the total market size over 2010-2013 was approximately 990.8 million people (of age 15-64). We use data on annual urban per capita income across all provinces from the China Statistical Year Book.

For further information about the vehicle characteristics in our data set, including descriptive statistics and graphs showing distributions of and trends in vehicles characteristics in the Chinese automobile market, see Chen, Lin Lawell and Wang (2020).

5. Results

5.1. Parameter estimates

The first-stage F-statistics are presented in Table A1 in the Appendix. For each endogenous variable, the first-stage F-statistic for that endogenous variable is obtained from a joint F-test of the instruments in a regression of that endogenous variable on all the instruments and controls. All the first-stage F-statistics are large; the first-stage F-statistics for seven out of the eight endogenous variables are greater than 10, and the remaining first-stage F-statistic is greater than 8. As explained above, the instrumental variables we use measure the exogenous degree of differentiation of each product in the market, and therefore circumvent the weak identification problem in demand models with flexible substitution patterns (Gandhi and Houde, 2020).

The results of two different specifications of our structural econometric model of supply and demand are reported in Table 2. Both our base-case Specification (1) and the alternative Specification (2) have the same specification for demand. On the cost side, Specification (2) has all the same terms as our base-case Specification (1), but also includes interactions between dummies for international joint ventures with each U.S. and Japan car company interacted with the technology-related car characteristics.

We discuss the results on the demand side first. In our base-case Specification (1), the standard deviations of the marginal utility of all the chosen vehicle characteristics except length are positive and significant, which suggests that consumers vary in how much they like different car characteristics other than length. The mean of the marginal utility of capacity is significant and negative, which suggests that on average, holding other characteristics such as length and weight constant, and within the range of capacity in the data (in the data the capacity ranges from 4 to 7 seats), people might prefer fewer seats in a car with a given length and weight, possibly because this may mean that all else equal each seat would then be larger. Nevertheless, the standard deviation of the marginal utility of capacity is significant and positive, which suggests that there is a distribution of consumers' preferences over car capacity, and therefore that some consumers might have a positive marginal utility of capacity and prefer more car seats even after holding vehicle length and weight constant. The means and standard deviations of the marginal utilities of all the chosen car characteristics in Specification (2) are quite similar to those in Specification (1), except the standard deviation of the marginal utility of length, which was insignificant in Specification (1) but becomes significant in Specification (2).

On the cost side, all the coefficients in the marginal cost on the chosen car characteristics are positive and significant in both Specifications (1) and (2). The coefficient on quantity is positive, significant, and similar in both specifications as well. Our finding of a slight diseconomy of scale in production over our 2010-2013 period of study is consistent with the results of Jiang et al. (2018), who find that many Chinese automobile firms had decreasing returns to scale over the period 2012-2014; and of Lu and Xia (2014), who find that several Chinese automobile firms had decreasing returns to scale in 2013.[11]

On the cost side, both Specifications (1) and (2) include dummies for having an international joint venture with each particular car company; interactions between the dummy for

[11] Our finding of a slight diseconomy of scale in production relies on the assumption the observed quantity sales is a good proxy for total production. This is a reasonable assumption since almost all domestic Chinese production is sold in China. Only around three percent of passenger cars produced in China were exported in 2019 (Ma, 2021), and the share of passenger car exports in the production output in China was even lower during 2010 to 2013 (Wong, 2021), our period of study.

having an international joint venture with technology-related vehicle characteristics; and dummies for having an international joint venture with a particular country interacted with technology-related vehicle characteristics. The signs of the coefficients on the dummies for having joint ventures with different international car companies are robust across specifications but are different from each other, indicating that forming joint ventures with different international car companies have different correlations with marginal cost.[12]

For both the U.S. and Japan, the coefficients on the terms that interact the international joint venture country dummies with the technology-related vehicle characteristics are all negative and significant in both specifications, which suggests that forming joint ventures with car companies from these two countries is associated with a lower marginal cost of technology-related vehicle characteristics on net, especially the marginal cost of making an alternative car. In contrast, forming joint ventures with international car companies from other countries is associated with a higher marginal cost of technology-related car characteristics on net.

The coefficients in marginal cost on the fuel economy policy interaction variables are quite similar across both specifications. The coefficient on the fuel economy standard minus fuel efficiency is positive and significant, which means that a firm incurs costs if it produces a car with worse fuel economy than the fuel economy standard, and also that a firm benefits if it produces a car with better fuel economy than the fuel economy standard. The coefficient on the dummy variable for the Corporate Average Fuel Consumption (CAFC) policy being in effect is positive and significant, which means that firms face higher marginal costs when the CAFC policy is in effect, possibly in part from the compliance costs of having to average the fuel efficiency over all their cars to meet the CAFC standard. The coefficient on the CAFC policy dummy interacted with the difference between the CAFC target and fuel efficiency is significant and positive, which means that a firm incurs costs from producing a car with worse fuel economy than the CAFC target when the CAFC is in place, perhaps because by doing so it then becomes harder for the firm to meet the CAFC.

[12] To the extent that international joint ventures are endogenous to the costs of a particular vehicle, the coefficients we estimate on international joint ventures may represent correlations rather than any causal relationship of the international joint venture on marginal cost. The endogeneity concern is mitigated in part because international joint ventures are formed at the firm level rather than at the vehicle level, as the marginal costs of a particular vehicle produced by a firm may not necessarily affect a firm's firm-level choice to form an international joint venture. Nevertheless, we do not interpret the coefficients on international joint ventures causally, but instead as representing correlations. We hope to analyze the firm-level decision to form international joint ventures in future work.

Finally, for the weights on different objectives in the state-owned firms' utility, results in both specifications suggest that almost all of the weight (92%) is on profit, with some weight on consumer surplus (6%) and a little weight on alternative vehicle production (2%). In our data set, the number of alternative vehicles produced in a firm-year across the 44 state-owned firms ranges from 0 to 7,302 alternative vehicles. Alternative vehicle production enters the alternative vehicle production objective of state-owned firms linearly, not quadratically, as the weight on the quadratic term is not statistically significant.

Since the parameter estimates in our base-case Specification (1) are robust to whether we include the interactions between dummies for international joint ventures with each U.S. and Japan car company interacted with the technology-related car characteristics in Specification (2), we focus on our base-case Specification (1) for the majority of our remaining analysis and counterfactual simulations. We discuss the additional terms in Specification (2) below.

5.2. Joint ventures with U.S. and Japanese car companies

In our base-case Specification (1), we find that the coefficients on the interactions between the dummies for forming international joint ventures with car companies from the U.S. and Japan and the technology-related variables (whether the car is an alternative vehicle, fuel efficiency, and horsepower) are all negative, which suggests that forming joint ventures with car companies from these two countries is associated with a lower marginal cost of technology-related vehicle characteristics on net, especially the marginal cost of making an alternative car. In contrast, forming joint ventures with international car companies from other countries is associated with a higher marginal cost of technology-related car characteristics on net.

To examine in detail the correlations between joint ventures with international car companies in these two countries and the marginal costs of the technology-related vehicle features, Specification (2) includes interactions between dummies for international joint ventures with each U.S. and Japan car company interacted with the technology-related car characteristics.[13]

[13] Both Specifications (1) and (2) already include dummies for having an international joint venture with each particular car company; interactions between the dummy for having an international joint venture with technology-related vehicle characteristics; and dummies for having an international joint venture with a particular country interacted with technology-related vehicle characteristics. Additionally including terms that interact dummies for international joint ventures with each car company with the technology-related car characteristics would result in too many parameters. Since we find in Specification (1) that the coefficients on the interactions between the dummies for forming international joint ventures with car companies from the U.S. and Japan and the technology-related variables

Using the parameter estimates from Specification (2) in Table 2, we examine the net correlations between forming joint ventures with each U.S. and Japan company and the marginal cost of each of the three chosen technology-related vehicle characteristics. The net correlations and their corresponding standard errors are summarized in Table 3. There are three notable patterns in the results. First, all the net correlations are negative, which means that forming joint ventures with car companies in the U.S. and Japan is associated with lower marginal costs of technology-related vehicle characteristics. Second, for fuel efficiency, the net correlations appear more negative for Japanese firms than for U.S. firms, which suggests that joint ventures with Japanese firms may be associated with more of a decrease in the marginal costs of fuel efficiency than joint ventures with U.S. firms are. Third, for horsepower, the opposite appears to be the case: in general, with the exception of Honda, the net correlations appear more negative for U.S. firms than for Japanese firms, which suggests that joint ventures with U.S. firms may be associated with more of a decrease in the marginal costs of horsepower than joint ventures with Japanese firms are.

To more formally compare the marginal costs of technology-related vehicle characteristics under joint ventures with Japanese firms with the marginal costs of technology-related vehicle characteristics under joint ventures with U.S. firms, we conduct two-sample t-tests. In particular, for each of the three technology-related vehicle characteristics (alternative vehicle, fuel efficiency, and horsepower), we conduct a two-sample t-test between the marginal costs of that technology-related vehicle characteristic under joint ventures with each respective Japanese firm, with the marginal costs of that technology-related vehicle characteristic under joint ventures with each respective U.S. firm. Tables 4a-4c present the difference in marginal costs of an alternative vehicle, fuel efficiency, and horsepower, respectively, under joint ventures with each respective Japanese firm and those under joint ventures with each respective U.S. firm, along with significance stars from each respective two-sample t-test.

The two-sample t-test results are consistent with the notable patterns in Table 3. As seen in Table 4a, with the exception of Mazda, the marginal costs of an alternative vehicle are lower in joint ventures with Japanese firms than they are in joint ventures with U.S. firms, and the differences are significant at a 0.1% level. As seen in Table 4b, the marginal costs of fuel

are all negative, we focus in Specification (2) on additionally including interactions between dummies for international joint ventures with each U.S. and Japan car company interacted with the technology-related car characteristics.

efficiency are lower in joint ventures with Japanese firms than they are in joint ventures with U.S. firms, and the differences are all significant at a 0.1% level. As seen in Table 4c, with the exception of Honda and Chrysler, the marginal costs of horsepower are lower in joint ventures with U.S. firms than they are in joint ventures with Japanese firms, and the differences are significant at a 0.1% level.

5.3. Welfare

In Table A2a in the Appendix, we present the welfare statistics calculated using the parameter estimates from base-case Specification (1) of Table 2 and actual data on prices, market shares, and vehicle characteristics. The welfare statistics we calculate include consumer surplus; total firm profits for private firms; average firm profits for private firms; total firm utility for state-owned firms, average firm utility for state-owned firms. Consumer surplus is calculated using equation (11); private firm profit is calculated using equation (8); and state-owned firm utility is calculated using equation (10).[14]

5.4. Model validation

To assess the goodness of fit of our model, we calculate statistics for costs, markups, and welfare for the base case in year 2013 using the parameter estimates from base-case Specification (1) of Table 2 applied to two different sets of data: (1) actual data for 2013 and (2) model predicted data for 2013 generated by using our estimated model to simulate (or predict) the data in 2013. The cost statistics we calculate include: mean marginal costs for alternative vehicles; mean marginal costs for each quartile of fuel efficiency; mean marginal costs for all cars. The markup statistics we calculate include: mean markups for alternative vehicles; mean markups for each quartile of fuel efficiency; mean markups for all cars. The welfare statistics we calculate include: consumer surplus; total firm profits for private firms; average firm profits for private firms; total firm utility for state-owned firms, average firm utility for state-owned firms. Marginal costs are calculated using equation (16); markups are calculated as the difference between price and

[14] We present the welfare statistics calculated using the parameter estimates from Specification (2) of Table 2 (instead of Specification (1) of Table 2) in Table A2b of the Appendix, and the welfare results are robust to whether we include interactions between dummies for international joint ventures with each U.S. and Japan car company and the technology-related car characteristics.

marginal cost; consumer surplus is calculated using equation (11); private firm profit is calculated using equation (8); and state-owned firm utility is calculated using equation (10).

The statistics based on actual data are calculated using actual data prices, market shares, and vehicle characteristics for year 2013. The statistics based on model predicted data for the base case are calculated by solving for a fixed point, since market shares are a function of price and prices are a function of market shares. With the model predicted market shares and prices and the actual vehicle characteristics, we are able to calculate the costs and welfare. We bootstrap the standard errors.

The statistics based on actual and model predicted data for cost, markups, and welfare are presented in Tables A3a-c, respectively, in the Appendix. As seen in these tables, our model does a fairly good job matching the statistics based on actual data.

To assess the importance of including random coefficients in our model of consumer demand, we also estimate our econometric model without random coefficients. The results are presented in Table A4 in the Appendix. As seen in Table A4, when random coefficients are excluded and consumers are not allowed to vary in how much they like different car characteristics, we estimate the wrong sign on some parameters, including the marginal utility for car capacity and some marginal costs parameters as well. Thus, using traditional logit demand models that do not include interactions between car characteristics and unobserved consumer characteristics would yield biased estimates of the parameters for the Chinese automobile market.

In our model of consumer demand, the marginal disutility of price is $\alpha + \alpha_y \frac{1}{y_i}$, with mean $\alpha + \alpha_y E\left[\frac{1}{y_i}\right]$. Under our assumption that income y_i is log normally distributed with mean μ_y and standard deviation σ_y, the mean marginal disutility of price is $\alpha + \alpha_y e^{-\mu_y + 0.5\sigma_y^2}$. Calibrating the mean μ_y and standard deviation σ_y empirically from data on annual urban per capita income (in Yuan) across all provinces from the China Statistical Year Book, and averaging over all years, we get $\mu_y = 9.9712$ and $\sigma_y = 0.1866$, which yields a mean marginal disutility of price of $\alpha + 0.00004754707\alpha_y$. For both specifications in Table 2, we have set $\alpha_y = 1$ and estimate α to be 0.420; the mean marginal disutility of price is therefore $0.42004754707 \approx 0.420$. Thus, as long as the magnitude of α_y is not very large, the mean marginal disutility of price is not affected much by α_y. As a consequence, our assumption that $\alpha_y = 1$ is unlikely to have a first-order effect on the parameter estimates or results. In Specification (4) in Table A5 in the Appendix, we further verify this by estimating an alternative version of our base-case Specification (1) in which we also estimate α_y instead of fixing it at $\alpha_y = 1$, and find that our estimate for α_y is 1.000 and our estimates for the remaining parameters remain the same as estimated in our base-case Specification (1) of Table 2. Thus our assumption that $\alpha_y = 1$ is unlikely to have a first-order effect on the parameter estimates or results.

6. Counterfactual Simulations

One advantage of estimating a structural econometric model is that we can use the estimated parameters to simulate demand, supply, and welfare under counterfactual scenarios. We use the parameters estimated from our structural model to run counterfactual simulations to analyze the effects on demand, cost, and welfare of counterfactual scenarios regarding state ownership and international joint ventures.

For each counterfactual scenario, we calculate statistics for market shares, costs, and welfare in 2013. The market share statistics we calculate include the total market share for all alternative vehicles. The cost statistics we calculate include the mean marginal costs for alternative vehicles, and the mean marginal costs for all cars. The welfare statistics we calculate include: consumer surplus; total firm profits for private firms; average firm profits for private firms; total firm utility for state-owned firms, average firm utility for state-owned firms. The simulated statistics are calculated by solving for a fixed point, since market shares are a function of price and prices are a function of market shares. We bootstrap the standard errors.

We assume that the parameters we estimate do not change under the different counterfactual scenarios. Since our utility parameters measure the marginal utility of different vehicle characteristics, including price, it seems reasonable to assume that the marginal utility of vehicle characteristics would not change under counterfactual scenarios regarding state ownership and international joint ventures, at least in the short run. Similarly, since the cost parameters already include parameters on interactions between international joint ventures and vehicle characteristics, it seems reasonable to assume that parameters in marginal costs would not change under counterfactual scenarios regarding state ownership and international joint ventures, at least in the short run. For the parameters in the objective function of state-owned firms, we assume the weights on the different terms in a state-owned firm's objective function and the parameters in alternative vehicle production objective would not change under counterfactual scenario regarding international joint ventures, at least in the short run. If anything, changes in state ownership and international joint ventures might be induced by parameters in consumer utility, firm costs, and/or the objectives of state-owned firms, rather than the other way around.

While we have endogenized each firm's choice of vehicle price, we take the vehicle characteristics as given and therefore assume that the vehicle characteristics do not change under the different counterfactual scenarios. We therefore focus on examining the short-run effects of counterfactual scenarios regarding state ownership and international joint ventures on equilibrium demand, cost, and welfare. In future work we hope to endogenize the choice of vehicle characteristics as well.

We simulate the effects of counterfactual scenarios regarding state ownership and international joint ventures on equilibrium demand, cost, and welfare. For each counterfactual scenario we simulate, we calculate statistics for market shares, costs, and welfare in 2013, and then conduct a two-sample t-test to compare each statistic from the new car scenario with the respective statistics from the base-case simulation of the status quo. The results are presented in Tables 5 and 6, which report, for each respective statistic (column), the difference between the statistic under the counterfactual simulation (row) and the statistic under the status quo base-case simulation.

6.1. *Counterfactual state ownership scenarios*

We first simulate and analyze counterfactual scenarios regarding state ownership. The first counterfactual state ownership scenario we simulate is privatization, in which we make all state-owned firms private. Thus, in this counterfactual scenario, we assume all firms care only about profit, and no firms put any weight on any other objective. As seen in Table 5, privatization has no significant effect on the alternative vehicle market share or on mean marginal costs for alternative vehicles, but leads to a significant increase in mean marginal costs for all cars. Privatization leads to a statistically significant increase in consumer surplus and in the average profits of firms that are actually state-owned in the data (but are now all privatized in this counterfactual privatization scenario), but no significant effect on the average firm profit of firms that were already private in the data (and remain private in this counterfactual privatization scenario).

A second counterfactual state ownership scenario we simulate is state ownership, in which we make all private firms state-owned. Thus, in this counterfactual state ownership scenario, we assume all firms have the objective functions of state-owned firms, with the parameters in the state-owned firm objective function as estimated from our structural model. As seen in Table 5, state ownership has a significant positive on the alternative vehicle market share, perhaps because the state-owned firms care about alternative vehicle production in addition to profit. State ownership leads to a significant increase in the mean marginal costs for alternative vehicles, but a significant decrease in mean marginal costs for all cars. Although state-owned firms care about consumer surplus, having all firms be state-owned leads to a statistically significant decrease in consumer surplus. Making all firms state-owned leads to a statistically significant increase in the average profits of firms that are actually private in the data (but are now all state-owned in this counterfactual state ownership scenario), but a statistically significant decrease in both the profits and utility of firms that were already state-owned in the data (and remain state-owned in this counterfactual state ownership scenario).

6.2. Counterfactual international joint venture scenarios

We next simulate and analyze counterfactual scenarios regarding international joint ventures. As the key potential contribution of international joint ventures that we focus on in our structural model is whether and how the marginal costs of technology-related vehicle characteristics are correlated with international joint ventures, which is a possible measure of whether Chinese automobile firms that form international joint ventures have better technology, our counterfactual international joint venture scenarios examine the short-run effects of these differences in marginal costs and technology on equilibrium demand, cost, and welfare. While we allow international joint ventures to lead to changes to marginal costs (reflecting changes in technology), we assume the vehicle characteristics do not change.

A first set of counterfactual international joint venture scenarios we simulate are counterfactual scenarios in which some or all of the actual international joint ventures in the data are no longer in existence (e.g., because the international joint venture was banned, or because it was no longer an option for whatever reason, or because it did not form). In particular, we simulate counterfactual scenarios in which there are no international joint ventures with (i) any country; (ii) any country except the U.S. or Japan; (iii) the U.S.; or (iv) Japan. In the counterfactual scenario in which there are no international joint ventures with any country (e.g., because international joint ventures are banned, or because none are formed), we assume that firms that previously had international joint ventures in the actual data now no longer have any international joint venture with any country. In the counterfactual scenario in which there are no international joint ventures with any country except Japan or the U.S., we assume that firms that previously had international joint ventures with any country other than Japan or the U.S. in the actual data now no longer have any international joint venture with any country. In the counterfactual scenario in which there are no international joint ventures with the U.S. (e.g., because international joint ventures with the U.S. are banned, or because they are no longer an option for whatever reason, or because none are formed), we assume that firms that previously had international joint ventures with the U.S. in the actual data now no longer have any international joint venture with any country. Similarly, in the counterfactual scenario in which there are no international joint ventures with Japan (e.g., because international joint ventures with Japan are banned, or because none are formed), we assume that firms that previously had international joint ventures with Japan in the actual data now no longer have any international joint venture with any country.

As seen in Table 6, when there are no international joint ventures with any country, or no international joint ventures with any country except the U.S. or Japan, then mean marginal costs increase for alternative vehicles and for all cars, consumer surplus decreases, and average private firm profit increases. In addition, when there are no international joint ventures with any country except the U.S. or Japan, both average state-owned firm profits and average state-owned firm utility decreases. Thus, both private and state-owned firms benefit when there are no international joint ventures with any country aside from Japan or the U.S., even though consumers do not and even though mean marginal costs are higher. When there are no international joint ventures with the U.S., or no international joint ventures with Japan, both average state-owned firm profits and average state-owned firm utility decreases.

A second set of counterfactual international joint venture scenarios we simulate are counterfactual scenarios in which all of the firms now all have international joint ventures with the same country (e.g., because all firms are required to form international joint ventures with this country, or because all firms choose to do so). In particular, we simulate counterfactual scenarios in which all the firms form international joint with (i) the U.S. only, or (ii) Japan only. In the counterfactual scenario in which all firms form international joint ventures with the U.S. only (e.g., because they are required to do so and because they all choose to do so), we assume that all firms that previously had international joint ventures with any country in the actual data now have their international joint venture with the U.S. (instead of any other country), and that all firms that previously did not have any international joint ventures with any country in the actual data now have an international joint venture with the U.S. Similarly, in the counterfactual scenario in which all firms form international joint ventures with Japan only (e.g., because they are required to do so, or because they all choose to do so), we assume that all firms that previously had international joint ventures with any country in the actual data now have their international joint venture with the Japan (instead of any other country), and that all firms that previously did not have any international joint ventures with any country in the actual data now have an international joint venture with the U.S. As seen in Table 6, we find that if all of the firms form international joint ventures either all with the U.S. or all with Japan, the alternative vehicle market share, average private firm profit, average state-owned firm profit, and average state-owned firm utility all increase. If all of the firms form international joint ventures with Japan, then consumer surplus increases as well.

7. Discussion and Conclusion

In this paper, we develop a random coefficients mixed oligopolistic differentiated products model of the Chinese automobile market that allows different consumers to vary in how much they like different car characteristics on the demand side, and that allows state-owned automobile companies to have different objectives from private automobile companies on the supply side. We model the behavior of not only private automobile companies but also the state-owned automobile companies in China. We incorporate international joint ventures, a notable feature of the Chinese automobile market. We estimate our model using a comprehensive data set on the sales, prices, and characteristics of the majority of vehicle makes and models in China. We use the model to analyze the effects of counterfactual scenarios regarding state ownership and international joint ventures on firms, consumers, and welfare.

According to our results, the standard deviations of the marginal utility of our chosen vehicle characteristics are statistically significant in all of the models specified, suggesting that it is important to allow for consumers to vary in how much they like different car characteristics.

We allow for the possibility that state-owned firms may care about objectives other than profit, and allow the data to tell us whether and how much state-owned firms care about these other objectives. Nevertheless, our empirical results for the weights on different objectives in the state-owned firms' utility show that almost all of the weight (92%) is on profit, with some weight on consumer surplus (6%) and a little weight on alternative vehicle production (2%). Thus, while state-owned car companies may care somewhat about other objectives such as consumer surplus and alternative vehicle production, their primary objective is to make profits. One possible reason why state-owned car companies still care primarily about profits despite being state-owned is that most state-owned car companies are not 100% state-owned. State-owned car companies that are partially state-owned might put less weight on government objectives and more weight on profit maximization. Another possible reason why state-owned car companies still care primarily about profits despite being state-owned is that, at least for the state-owned firms that form international joint ventures, the international joint venture is at least partially controlled by the international car company (Hu, Xiao and Zhou, 2014), who may care primarily about profits; as a consequence, the realized pricing decisions of state-owned firms that form international joint ventures may be those that maximize primarily profits. A third possible reason why state-owned car companies still care primarily about profits is that the state-owned companies may only care about the utilities of a subset of consumers, instead of all consumers, and thus might put less weight on the consumer surplus for all consumers.

One notable feature of Chinese automobile industry is that a number of domestic car companies form joint ventures with international car companies. Our results show that Chinese car companies that form international joint ventures with car companies in the U.S. and Japan have lower marginal costs of technology-related vehicle characteristics such as whether the car is an alternative vehicle, fuel efficiency, and horsepower. In contrast, Chinese car companies that form joint ventures with international car companies from other countries have higher marginal costs of technology-related car characteristics. Thus, Chinese automobile firms that form international joint ventures with firms in the U.S. and Japan have better technology, while those that form joint ventures with international car companies from other countries do not.

When comparing international joint ventures with car companies in the U.S. and Japan, we find that for fuel efficiency, the marginal costs of fuel efficiency are lower in joint ventures with Japanese firms than they are in joint ventures with U.S. firms. Similarly, with the exception of Mazda, the marginal costs of an alternative vehicle are lower in joint ventures with Japanese firms than they are in joint ventures with U.S. firms. For horsepower, the opposite appears to be the case: in general, with the exception of Honda and Chrysler, the marginal costs of horsepower are lower in joint ventures with U.S. firms than they are in joint ventures with Japanese firms. These results suggest a possible comparative advantage in horsepower technology among U.S. firms, and a possible comparative advantage in fuel efficiency technology among Japanese firms; which may in turn reflect a possible relative preference for horsepower in the U.S., and a possible relative preference for fuel efficiency in Japan.

In the previous literature, Jiang et al. (2020) find evidence that, in all industries in China, Chinese firms that form international joint ventures benefit from indirect technology transfers that enable them to perform better. Our results on international joint ventures builds on Jiang et al. (2020) by finding a more nuanced result for the Chinese automobile industry: whether or not Chinese automobile companies that form an international joint venture have higher or lower marginal costs of technology-related vehicle characteristics depends on the headquarter country of the international car company with which the Chinese automobile company forms a joint venture.

Our results that Chinese car companies that form international joint ventures with car companies in the U.S. and Japan have lower marginal costs of technology-related vehicle characteristics and therefore appear to have better technology are also consistent with the theoretical results of Schmitz (2019), who finds that joint ownership and joint ventures may be optimal for activities involving R&D, innovation, and/or technology. Our results are also congruous with the descriptive and reduced-form empirical evidence in Bai et al. (2020) that vehicle models produced by different international joint ventures have differential quality strengths reflecting the quality strengths of the international car company from which the Chinese automobile learns via the joint venture, and that these patterns are consistent the common perception that German brands have prime engine performance while Japanese brands are more fuel efficient.

Some possible sources of differences between international car companies from different countries that may explain these differences in marginal costs include differences in intellectual property rights protection and laws; differences in automobile regulations (such as fuel economy regulations); differences in technology; differences in efficiency; different motivations for entering the Chinese automobile market; different motivations for forming international joint ventures with Chinese automobile companies; and differences in the types of vehicles produced by international car companies from different countries, possibly reflecting different distributions of consumer preferences in different countries.

Our counterfactual simulations yield several main results. First, privatizing all firms increases consumer surplus and the average profits of firms that were previously state-owned in the data (but are now all privatized in the counterfactual privatization scenario), but has no significant effect on the average firm profit of firms that were already private in the data (and remain private in the counterfactual privatization scenario), the alternative vehicle market share, or the mean marginal costs for alternative vehicles.

A second result from our counterfactual simulations is that both private and state-owned firms benefit when there are no international joint ventures with any country aside from Japan or the U.S., even though consumers do not and even though mean marginal costs are higher. If all of the firms form international joint ventures either all with the U.S. or all with Japan, the alternative vehicle market share, average private firm profit, average state-owned firm profit, and average state-owned firm utility all increase. If all of the firms form international joint ventures with Japan, then consumer surplus increases as well.

Our results therefore show that Chinese car companies that form international joint ventures with car companies in the U.S. and Japan have lower marginal costs of technology-related vehicle characteristics such as whether the car is an alternative vehicle, fuel efficiency, and horsepower; and suggest that private firms, state-owned firms, the alternative vehicle market, and possibly consumers as well would all benefit if all of the firms form international joint ventures with the U.S. or Japan. In contrast, Chinese car companies that form joint ventures with international car companies from other countries have higher marginal costs of technology-related car characteristics.

Our research points to several potential avenues for future research. First, to the extent that international joint ventures are endogenous to the costs of a particular vehicle, the coefficients we estimate on international joint ventures may represent correlations rather than any causal relationship of the international joint venture on marginal cost. The endogeneity concern is mitigated in part because international joint ventures are formed at the firm level rather than at the vehicle level, as the marginal costs of a particular vehicle produced by a firm may not necessarily affect a firm's firm-level choice to form an international joint venture. Nevertheless, we do not interpret the coefficients on international joint ventures causally, but instead as representing correlations. We hope to analyze the firm-level decision to form international joint ventures in future work, building on Siebert (2017), who develops a structural model of the impact of research joint ventures on innovation and product market efficiency.

A second potential avenue for future research is to model a firm's choice of vehicle characteristics for each vehicle they produce. In this paper, we have endogenized each firm's choice of vehicle price, but have taken the vehicle characteristics as given in both our structural estimation and our counterfactual simulations. It is possible that the choice of vehicle characteristics may depend on whether the firm is state-owned and also on whether the firm has formed an international joint venture. In future work we hope to endogenize the choice of vehicle characteristics as well.

A third potential avenue for future research is to model the dynamic decision-making of the firms, including their dynamic decisions to introduce new cars and form international joint ventures. In this paper, following the previous literature, we have modeled the decisions of both private and state-owned firms as a static game. In future work we hope to model the firms' decisions as a dynamic game.

A fourth potential avenue for future research is to also incorporate the dynamics of the used car market, building on the models of Busse, Knittel and Zettelmeyer (2013); and the dynamic decision-making of consumers, including the decision to scrap older vehicles and the joint decisions of vehicle ownership and vehicle usage (vehicle miles driven), building on the models of Gillingham et al. (2021) and Li, Liu and Wei (2021). When considering the dynamic impacts in the used car market, Jacobsen (2013) finds that the overall welfare costs of the U.S. Corporate Average Fuel Economy (CAFE) standards are regressive. Bento et al. (2020) find that including multi-market interactions involving the used car market and scrappage are important for providing accurate predictions of the costs and benefits of fuel economy standards.

Fifth, while our structural econometric model of a mixed oligopolistic differentiated products market allows different consumers to vary in how much they like different car characteristics on the demand side, it is estimated using product-level and aggregate market-level data, since our comprehensive data set on the sales, prices, and characteristics of the majority of vehicle makes and models in China, including alternative vehicles, is at the aggregate market level. Berry, Levinsohn and Pakes (2004) show how rich sources of consumer-level information on vehicle choice can help to identify demand parameters in a widely-used class of differentiated products demand models. Disaggregate models of vehicle choice using consumer-level data for the U.S. automobile market have enabled previous researchers to incorporate and analyze additional realistic features such as brand loyalty (Train and Winston, 2007) and the intergenerational transmission of brand preferences (Anderson et al., 2015). In future work we hope to find and obtain consumer-level vehicle choice data for the Chinese automobile market that would enable us to further refine our model of vehicle demand to incorporate and analyze additional realistic features of vehicle choice. Having more disaggregated data would also enable us to better incorporate features such as local protectionism (Barwick, Cao and Li, 2021), to analyze the effects of any local government policies, to allow state-owned car companies that are partially owned by a local government rather than the central government to possibly care about local consumer surplus instead of national consumer surplus, and to allow state-owned car companies that are partially owned by a local government to possibly have objectives that may differ from state-owned companies that are partially owned by the central government.

Our model of the demand and cost in the Chinese automobile market has implications for industry, particularly car manufacturers interested in better targeting cars, including alternative vehicles, for the Chinese market. In ongoing, complementary work, for example, Chen and Lin Lawell (2021a) use the structural econometric model of a mixed oligopolistic differentiated products market that we have developed of the Chinese automobile market to simulate and analyze the effects of introducing a new alternative vehicle on alternative vehicle market share and welfare.

In addition, our estimates of the factors that affect demand and supply in the Chinese automobile market have important implications for policy-makers interested in developing incentive policies to increase market penetration of alternative vehicles with potential environmental and climate benefits. In ongoing, complementary work, for example, Chen and Lin Lawell (2021b) use the structural econometric model of a mixed oligopolistic differentiated products market that we have developed of the Chinese automobile market to simulate and analyze the effects of counterfactual fuel efficiency policies on alternative vehicle market share and welfare.

Our research and the model we have developed of demand and supply in the Chinese automobile market have important implications for industry, government, society, academia, and NGOs.

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Table 1a. Summary statistics, 2010-2013

Variable	# Obs	Mean	Std. Dev.	Min	Max
Price (1,000 Yuan)	2,215	158.40	119.87	28.8	899.6
Quantity	2,215	51,986.65	53,832.95	1	263,408
Alternative vehicle (dummy)	2,215	0.003	0.052	0	1
Fuel efficiency (100 km/L)	2,215	0.134	0.021	0.078	0.233
Length (mm)	2,215	4,500.09	319.83	3,400	5,175
Weight (kg)	2,215	1,373.05	235.89	815	2,310
Capacity (number of seats)	2,215	5.093	0.432	4	7
Horsepower (PS)	2,215	137.33	41.22	46	310

Table 1b. Summary statistics for state-owned firms, 2010-2013

Variable	# Obs	Mean	Std. Dev.	Min	Max
Price (1,000 Yuan)	1,640	166.34	109.70	28.8	899.6
Quantity	1,640	53,786.43	56,688.37	1	263,408
Alternative vehicle (dummy)	1,640	0.004	0.060	0	1
Fuel efficiency (100 km/L)	1,640	0.131	0.819	0.078	0.233
Length (mm)	1,640	4,513.88	307.22	3,400	5,175
Weight (kg)	1,640	1,376.36	225.92	815	2,310
Capacity (number of seats)	1,640	5.099	0.447	4	7
Horsepower (PS)	1,640	137.48	40.00	46	310

Table 1c. Summary statistics for private firms, 2010-2013

Variable	# Obs	Mean	Std. Dev.	Min	Max
Price (1,000 Yuan)	575	135.76	142.71	33.8	797.6
Quantity	575	46,853.55	44,343.03	37	217,842
Alternative vehicle (dummy)	575	0	0	0	0
Fuel efficiency (100 km/L)	575	0.132	0.804	0.093	0.196
Length (mm)	575	4,460.76	350.64	3,460	5,039
Weight (kg)	575	1,363.61	262.24	870	1,950
Capacity (number of seats)	575	5.073	0.389	4	7
Horsepower (PS)	575	134.03	44.42	68	306

Table 2. Results of random coefficients mixed oligopolistic differentiated products model of supply and demand, 2010-2013

	(1)	(2)
Mean β of marginal utility of:		
Alternative vehicle (dummy)	0.106***	0.106***
	(0.001)	(0.012)
Fuel efficiency (100km/L)	0.235***	0.235***
	(0.002)	(0.003)
Length (m)	0.294***	0.294***
	(0.004)	(0.006)
Weight (metric ton)	0.281***	0.281***
	(0.001)	(0.002)
Capacity (number of seats)	-0.133***	-0.133***
	(0.002)	(0.004)
Horsepower (PS)	0.168***	0.168***
	(0.005)	(0.009)
Constant	0.333***	0.333***
	(0.000)	(0.003)
Standard deviation σ of marginal utility of:		
Alternative vehicle (dummy)	0.163***	0.163***
	(0.003)	(0.002)
Fuel efficiency (100km/L)	0.112***	0.112***
	(0.001)	(0.004)
Length (m)	0.009	0.009**
	(0.007)	(0.003)
Weight (metric ton)	0.347***	0.347***
	(0.004)	(0.005)
Capacity (number of seats)	0.105***	0.105***
	(0.000)	(0.007)
Horsepower (0.01PS)	0.029***	0.029***
	(0.001)	(0.008)
Constant	0.210***	0.210***
	(0.002)	(0.004)
Parameter α in marginal disutility of price (1,000 Yuan)	0.420***	0.420***
	(0.000)	(0.000)
Coefficient γ in marginal cost on:		
Alternative vehicle (dummy)	0.139***	0.139***
	(0.003)	(0.002)
Fuel efficiency (100km/L)	0.060***	0.060***
	(0.000)	(0.005)
Length (m)	0.126***	0.126***
	(0.003)	(0.010)
Weight (metric ton)	0.101***	0.101***
	(0.003)	(0.004)
Capacity (number of seats)	0.156***	0.156***

	(0.002)	(0.003)
Horsepower (0.01PS)	0.113***	0.113***
	(0.003)	(0.010)
State-owned (dummy)	0.111***	0.111***
	(0.005)	(0.002)
Constant	0.245***	0.245***
	(0.006)	(0.003)
Coefficient η in marginal cost on quantity	0.007***	0.007***
	(0.000)	(0.001)
Coefficient Γ in marginal cost on joint venture with:		
Mazda	0.158***	0.158***
	(0.000)	(0.003)
Honda	-0.064***	-0.064***
	(0.006)	(0.003)
Daihatsu	0.054***	0.054***
	(0.004)	(0.001)
Toyota	0.219***	0.219***
	(0.004)	(0.007)
Suzuki	-0.028***	-0.028**
	(0.005)	(0.010)
Nissan	0.033***	0.033***
	(0.000)	(0.002)
Mitsubishi	0.185***	0.185***
	(0.000)	(0.001)
Isuzu	-0.110***	-0.110***
	(0.007)	(0.007)
Daimler	-0.224***	-0.224***
	(0.002)	(0.003)
BMW	-0.059***	-0.059***
	(0.001)	(0.004)
Volkswagen	0.035***	0.035***
	(0.000)	(0.006)
Audi	0.092***	0.092***
	(0.007)	(0.004)
Lotus	-0.253***	-0.253***
	(0.004)	(0.005)
GM	-0.189***	-0.189***
	(0.005)	(0.006)
Ford	0.029***	0.029***
	(0.003)	(0.005)
Chrysler	-0.135***	-0.135***
	(0.006)	(0.005)
Hyundai	0.003	0.003
	(0.008)	(0.006)
Kia	-0.115***	-0.115***
	(0.001)	(0.011)
Volvo	0.134***	0.134***
	(0.001)	(0.005)
Saab	0.193***	0.193***
	(0.001)	(0.005)

PSA	-0.31***	-0.31***
	(0.001)	(0.000)
Fiat	-0.382***	-0.382***
	(0.000)	(0.004)
Coefficients in marginal cost on international joint venture-technology interactions:		
Has international joint venture * alternative vehicle	0.144***	0.144***
	(0.001)	(0.008)
Has international joint venture * fuel efficiency	-0.160***	-0.160***
	(0.005)	(0.005)
Has international joint venture * horsepower	-0.073***	-0.073***
	(0.003)	(0.008)
Coefficients in marginal cost on international joint venture country-technology interactions:		
Japan * alternative vehicle	-0.420***	-0.420***
	(0.003)	(0.003)
Japan * fuel efficiency	-0.713***	-0.713***
	(0.003)	(0.004)
Japan * horsepower	-0.851***	-0.851***
	(0.002)	(0.004)
Germany * alternative vehicle	0.118***	0.118***
	(0.001)	(0.005)
Germany * fuel efficiency	0.708***	0.708***
	(0.002)	(0.003)
Germany * horsepower	0.774***	0.774***
	(0.005)	(0.001)
Britain * alternative vehicle	1.005***	1.005***
	(0.002)	(0.004)
Britain * fuel efficiency	0.213***	0.213***
	(0.003)	(0.004)
Britain * horsepower	0.615***	0.615***
	(0.003)	(0.003)
US * alternative vehicle	-0.203***	-0.203***
	(0.002)	(0.004)
US * fuel efficiency	-0.149***	-0.149***
	(0.009)	(0.004)
US * horsepower	-0.662***	-0.662***
	(0.002)	(0.002)
South Korea * alternative vehicle	0.445***	0.445***
	(0.002)	(0.002)
South Korea * fuel efficiency	0.678***	0.678***
	(0.002)	(0.004)
South Korea * horsepower	0.361***	0.361***
	(0.001)	(0.010)

Sweden * alternative vehicle	0.981***	0.981***
	(0.004)	(0.004)
Sweden * fuel efficiency	0.748***	0.748***
	(0.002)	(0.004)
Sweden * horsepower	0.912***	0.912***
	(0.001)	(0.001)
France * alternative vehicle	0.268***	0.268***
	(0.010)	(0.007)
France * fuel efficiency	0.437***	0.437***
	(0.002)	(0.007)
France * horsepower	0.203***	0.203***
	(0.000)	(0.003)
Italy * alternative vehicle	0.098***	0.098***
	(0.002)	(0.002)
Italy * fuel efficiency	0.336***	0.336***
	(0.002)	(0.003)
Italy * horsepower	1.042***	1.042***
	(0.000)	(0.004)
Coefficients in marginal cost on international joint venture company-technology interactions:		
Mazda * fuel efficiency		-0.182***
		(0.006)
Mazda * horsepower		-0.264***
		(0.003)
Mazda * alternative vehicle		-0.146***
		(0.004)
Honda * fuel efficiency		-0.136***
		(0.006)
Honda * horsepower		-0.869***
		(0.001)
Honda * alternative vehicle		-0.580***
		(0.003)
Daihatsu * fuel efficiency		-0.550***
		(0.002)
Daihatsu * horsepower		-0.145***
		(0.004)
Daihatsu * alternative vehicle		-0.853***
		(0.003)
Toyota * fuel efficiency		-0.622***
		(0.003)
Toyota * horsepower		-0.351***
		(0.003)
Toyota * alternative vehicle		-0.513***
		(0.001)
Suzuki * fuel efficiency		-0.402***
		(0.008)

Suzuki * horsepower		-0.076***
		(0.008)
Suzuki * alternative vehicle		-0.240***
		(0.002)
Nissan * fuel efficiency		-0.123***
		(0.007)
Nissan * horsepower		-0.184***
		(0.006)
Nissan * alternative vehicle		-0.240***
		(0.004)
Mitsubishi * fuel efficiency		-0.417***
		(0.005)
Mitsubishi * horsepower		-0.050***
		(0.009)
Mitsubishi * alternative vehicle		-0.903***
		(0.002)
Isuzu * fuel efficiency		-0.945***
		(0.007)
Isuzu * horsepower		-0.491***
		(0.004)
Isuzu * alternative vehicle		-0.489***
		(0.003)
GM * fuel efficiency		-0.338***
		(0.008)
GM * horsepower		-0.900***
		(0.003)
GM * alternative vehicle		-0.369***
		(0.001)
Ford * fuel efficiency		-0.111***
		(0.005)
Ford * horsepower		-0.780***
		(0.006)
Ford * alternative vehicle		-0.390***
		(0.003)
Chrysler * fuel efficiency		-0.242***
		(0.003)
Chrysler * horsepower		-0.404***
		(0.005)
Chrysler * alternative vehicle		-0.096***
		(0.005)
Coefficients in marginal cost on fuel efficiency policy variables:		
Difference between fuel economy target and actual fuel efficiency (100km/L)	0.547***	0.547***
	(0.004)	(0.007)
Corporate Average Fuel Consumption (CAFC) policy is in effect (dummy)	0.279***	0.279***
	(0.003)	(0.002)

CAFC policy dummy * Difference between Corporate Average Fuel Consumption (CAFC) target and actual fuel efficiency (100km/L)	0.958***	0.958***
	(0.006)	(0.003)
Weights on objectives in state-owned firms' utility:		
ρ_1 weight on profit	0.920***	0.920***
	(0.002)	(0.005)
ρ_2 weight on consumer surplus	0.060***	0.060***
	(0.000)	(0.002)
$(1-\rho_1-\rho_2)$ weight on alternative vehicle production	0.020***	0.020***
	(0.002)	(0.006)
Parameters in alternative vehicle production objective in state-owned firms' utility:		
λ_1 weight on quadratic term in alternative vehicle production objective	0.050	0.050
	(0.544)	(0.190)
λ_2 constant in quadratic term in alternative vehicle production objective	150***	150***
	(0.000)	(0.000)
# Observations	2,215	2,215

Notes: Standard errors are reported in parentheses. Significance codes: * p<0.05; ** p<0.01; ***p<0.001.

Table 3. Net correlations between forming joint ventures with each U.S. and Japan car company and the marginal cost of the technology-related vehicle characteristics

	Alternative Vehicle	Fuel Efficiency	Horsepower
Japanese firms			
Mazda	-0.422***	-1.055***	-1.188***
	(0.009)	(0.009)	(0.010)
Honda	-0.856***	-1.009***	-1.793***
	(0.009)	(0.009)	(0.009)
Daihatsu	-1.129***	-1.423***	-1.069***
	(0.009)	(0.007)	(0.009)
Toyota	-0.789***	-1.495***	-1.275***
	(0.009)	(0.007)	(0.009)
Suzuki	-0.516***	-1.275***	-1.000***
	(0.009)	(0.010)	(0.012)
Nissan	-0.460***	-0.996***	-1.108***
	(0.009)	(0.009)	(0.011)
Mitsubishi	-1.179***	-1.290***	-1.108***
	(0.009)	(0.008)	(0.013)
Isuzu	-0.765***	-1.818***	-1.415***
	(0.009)	(0.009)	(0.010)
U.S. firms			
GM	-0.428***	-0.647***	-1.635***
	(0.009)	(0.010)	(0.009)
Ford	-0.449***	-0.420***	-1.515***
	(0.009)	(0.008)	(0.011)
Chrysler	-0.155***	-0.551***	-1.139***
	(0.010)	(0.007)	(0.010)

Notes: Table reports net correlations between forming joint ventures with each respective U.S. and Japan car company (row) and the marginal cost of each respective technology-related vehicle characteristic (column). Net correlations are calculated using parameter estimates from Specification (2) of Table 2. Standard errors are reported in parentheses. Significance codes: * p<0.05; ** p<0.01; *** p<0.001

Table 4a. Differences between joint ventures with Japanese vs. U.S. firms in marginal costs of an alternative vehicle

	GM	Ford	Chrysler
Mazda	0.0060***	0.0270***	-0.2670***
Honda	-0.4280***	-0.4280***	-0.7010***
Daihatsu	-0.7010***	-0.7010***	-0.9740***
Toyota	-0.3610***	-0.3610***	-0.6340***
Suzuki	-0.0880***	-0.0880***	-0.3610***
Nissan	-0.0320***	-0.0320***	-0.3050***
Mitsubishi	-0.7510***	-0.7510***	-1.0240***
Isuzu	-0.3370***	-0.3370***	-0.6100***

Notes: Table presents differences in marginal costs of an alternative vehicle between international joint ventures with each respective Japanese firm (row) and each respective U.S. firm (column). Net correlations between forming international joint ventures with each respective Japanese and U.S. firm and the marginal cost of an alternative vehicle are from Table 3, which are calculated using parameter estimates from Specification (2) of Table 2. Significance stars following the difference indicates the significance of a two-sample t-test of the difference between the marginal costs of an alternative vehicle under a joint venture with the respective Japanese firm (row) and the marginal costs of an alternative vehicle under a joint venture with the respective U.S. firm (column). Significance codes: * $p<0.05$; ** $p<0.01$; *** $p<0.001$

Table 4b. Differences between joint ventures with Japanese vs. U.S. firms in marginal costs of fuel efficiency

	GM	Ford	Chrysler
Mazda	-0.4080***	-0.6350***	-0.5040***
Honda	-0.3620***	-0.5890***	-0.4580***
Daihatsu	-0.7760***	-1.0030***	-0.8720***
Toyota	-0.8480***	-1.0750***	-0.9440***
Suzuki	-0.6280***	-0.8550***	-0.7240***
Nissan	-0.3490***	-0.5760***	-0.4450***
Mitsubishi	-0.6430***	-0.8700***	-0.7390***
Isuzu	-1.1710***	-1.3980***	-1.2670***

Notes: Table presents differences in marginal costs of fuel efficiency between international joint ventures with each respective Japanese firm (row) and each respective U.S. firm (column). Net correlations between forming international joint ventures with each respective Japanese and U.S. firm and the marginal cost of fuel efficiency are from Table 3, which are calculated using parameter estimates from Specificion (2) of Table 2. Significance stars following the difference indicates the significance of a two-sample t-test of the difference between the marginal costs of fuel efficiency under a joint venture with the respective Japanese firm (row) and the marginal costs of fuel efficiency under a joint venture with the respective U.S. firm (column). Significance codes: * $p<0.05$; ** $p<0.01$; ***$p<0.001$

Table 4c. Differences between joint ventures with Japanese vs. U.S. firms in marginal costs of horsepower

	GM	Ford	Chrysler
Mazda	0.4470***	0.3270***	-0.0490***
Honda	-0.1580***	-0.2780***	-0.6540***
Daihatsu	0.5660***	0.4460***	0.0700***
Toyota	0.3600***	0.2400***	-0.1360***
Suzuki	0.6350***	0.5150***	0.1390***
Nissan	0.5270***	0.4070***	0.0310***
Mitsubishi	0.5270***	0.4070***	0.0310***
Isuzu	0.2200***	0.1000***	-0.2760***

Notes: Table presents differences in marginal costs of horsepower between international joint ventures with each respective Japanese firm (row) and each respective U.S. firm (column). Net correlations between forming international joint ventures with each respective Japanese and U.S. firm and the marginal cost of horsepower are from Table 3, which are calculated using parameter estimates from Specificion (2) of Table 2. Significance stars following the difference indicates the significance of a two-sample t-test of the difference between the marginal costs of horsepower under a joint venture with the respective Japanese firm (row) and the marginal costs of horsepower under a joint venture with the respective U.S. firm (column). Significance codes: * p<0.05; ** p<0.01; ***p<0.001

Table 5. Counterfactual state ownership scenarios

	Difference from status quo base case in:						
	Alternative vehicle market share	Mean marginal costs for alternative vehicles (1000 Yuan)	Mean marginal costs for all cars (1000 Yuan)	Consumer surplus (1000 Yuan)	Average private firm profit (billion Yuan)	Average state-owned firm profit (billion Yuan)	Average state-owned firm utility (billion Yuan)
Privatization	0.0000	-1.85	25.97***	229.10***	4.35	9.86***	
State ownership	0.0004***	87.20***	-20.83***	-838.92***	88.84***	-8.91***	-9.60***

Notes: Table reports, for each respective statistic (column), the difference between the statistic under the counterfactual simulation (row) and the statistic under the status quo base-case simulation. In this Table, "private firm" and "state-owned firm" refers to whether the firm is private or state-owned in the actual data. Thus, for private firm profit, we are comparing the firm profits under the counterfactual simulation with that under the status quo base-case simulation for the firms that were private in the actual data; and for state-owned firm profit and utility, we are comparing the firm profits and utility under the counterfactual simulation with that under the status quo base-case simulation for the firms that were state-owned in the actual data. For example, for the counterfactual privatization scenario, the statistics for average private firm profit are calculated using firms that were already private in the data (and remain private in the counterfactual privatization scenario), while the statistics for average state-owned firm profit are calculated for firms that are actually state-owned in the data (but are now all privatized in this counterfactual privatization scenario). Similarly, for the counterfactual state ownership scenario, the statistics for average private firm profit are calculated using firms that were already private in the data (but are now all state-owned in this counterfactual state ownership scenario), while the statistics for average state-owned firm profit and average state-owned firm utility are calculated for firms that are actually state-owned in the data (and remain state-owned in this counterfactual state ownership scenario). Significance stars following the difference from base case indicates the significance of a two-sample t-test of the difference between the statistic in the counterfactual simulation and that in the base-case simulation. Significance codes: * p<0.05; ** p<0.01; ***p<0.001

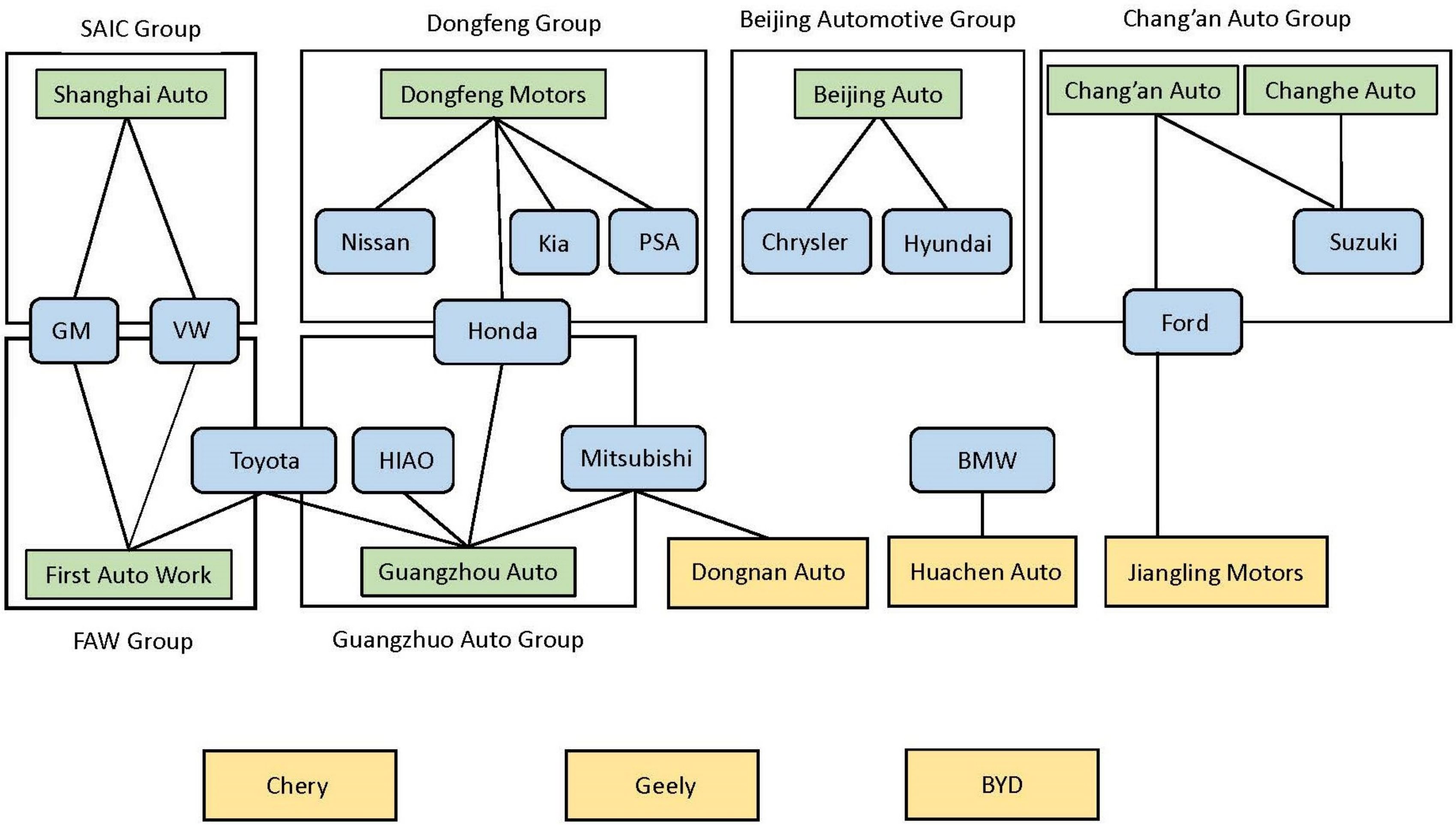
Table 6. Counterfactual international joint venture scenarios

	Difference from status quo base case in:						
	Alternative vehicle market share	Mean marginal costs for alternative vehicles (1000 Yuan)	Mean marginal costs for all cars (1000 Yuan)	Consumer surplus (1000 Yuan)	Average private firm profit (billion Yuan)	Average state-owned firm profit (billion Yuan)	Average state-owned firm utility (billion Yuan)
No international joint ventures with:							
Any country	0.0017***	418.46***	32.24***	-485.48***	216.32***	0.13	-0.69
Any country except U.S. or Japan	0.0018***	442.63***	108.95***	-103.64***	246.91***	28.65***	26.19***
U.S.	0.0000	-0.53	-24.58***	44.67	-4.10	-8.69***	-7.93***
Japan	0.0000	-3.11	-22.75***	-481.35***	6.98*	-11.62***	-11.49***
All firms have international joint ventures with:							
U.S. only	0.0061***	1,519.74***	338.58***	-119.93***	834.82***	75.40***	69.17***
Japan only	0.0087***	2,165.84***	496.88***	137.08***	1201.87***	110.61***	101.98***

Notes: Table reports, for each respective statistic (column), the difference between the statistic under the counterfactual simulation (row) and the statistic under the status quo base-case simulation. Significance stars following the difference from base case indicates the significance of a two-sample t-test of the difference between the statistic in the counterfactual simulation and that in the base-case simulation. Significance codes: * $p<0.05$; ** $p<0.01$; *** $p<0.001$

Appendix A. Supplementary Figures and Tables

Figure A1. Market Structure of Chinese Automobile Industry, 2010-2013



Notes: This figure is a rough sketch of the market structure among some of the main firms in the Chinese automobile industry during the 2010-2013 time period of our study. Chinese firms that are at least partially state-owned are in green. Private Chinese firms are in yellow. International car companies are in blue. Lines connecting firms indicate joint ventures between firms. The large boxes around state-owned firms and the international car companies with which they form joint ventures indicate the largest state-owned automobile groups in China.
Data Sources: Hu, Xiao and Zhou (2014); baike.baidu.com; China Industry Business Performance Data.

Table A1. First-stage F-statistics

Endogenous Variable	First-Stage F-Statistic
Price	47.90
Alternative Fuel Vehicle	10.11
Fuel Efficiency	24.39
Length	46.36
Weight	39.77
Capacity	474.88
Horsepower	56.09
Quantity	8.12

Instruments

Number of cars with similar values of:
- Fuel efficiency
- Length
- Weight
- Capacity
- Horsepower

Value for the closest car of:
- Fuel efficiency
- Length
- Weight
- Horsepower

Value for the closest car with a different model-year-displacement of:
- Fuel efficiency
- Length
- Weight

Fraction of other cars that year that are alternative vehicles

Has international joint venture dummy interacted with:
- Fraction of other cars that year that are alternative vehicles
- Number of cars with similar values of fuel efficiency
- Number of cars with similar values of horsepower

Dummy for joint venture with company in:
- Japan
- Germany
- Great Britain
- U.S.
- South Korea
- Sweden
- France
- Italy

interacted with:
- Fraction of other cars that year that are alternative vehicles
- Number of cars with similar values of fuel efficiency
- Number of cars with similar values of horsepower

Difference between fuel economy target and the number of cars with similar values of fuel efficiency

Difference between Corporate Average Fuel Consumption (CAFC) target and the number of cars with similar values of fuel efficiency, interacted with dummy for being required to meet CAFC target

Note: For each endogenous variable, the first-stage F-statistic for that endogenous variable is obtained from a joint F-test of the instruments in a regression of that endogenous variable on all the instruments and controls.

Table A2a. Welfare for Specification (1) of Table 2

	2010	2011	2012	2013
Consumer surplus	0.0139***	0.0072***	0.0008***	0.0026***
	(0.0006)	(0.0003)	(0.0000)	(0.0001)
Total firm profit for private firms	862.82***	613.69***	787.00***	1,944.60***
	(0.14)	(0.09)	(0.77)	(0.22)
Average firm profit for private firms	86.28***	61.37***	87.45***	216.07***
	(0.01)	(0.01)	(0.01)	(0.03)
Total firm utility for state-owned firms	1,993.10***	2,902.40***	3,036.40***	4,156.60***
	(5.47)	(7.90)	(8.08)	(11.22)
Average firm utility for state-owned firms	76.66***	100.08***	97.95***	115.46***
	(0.21)	(0.27)	(0.26)	(0.31)

Notes: All values are in units of billion Yuan. Welfare is calculated using parameter estimates from Specification (1) of Table 2. Standard errors are reported in parentheses. Significance codes: * p<0.05; ** p<0.01; ***p<0.001

Table A2b. Welfare for Specification (2) of Table 2

	2010	2011	2012	2013
Consumer surplus	0.0139***	0.0072***	0.0008***	0.0026***
	(0.0012)	(0.0006)	(0.0001)	(0.0002)
Total firm profit for private firms	862.82***	613.69***	787.08***	1944.60***
	(0.60)	(0.38)	(0.33)	(0.94)
Average firm profit for private firms	86.28***	61.37***	87.45***	216.07***
	(0.06)	(0.04)	(0.04)	(0.10)
Total firm utility for state-owned firms	2165.50***	3154.30***	3300.40***	4517.90***
	(1.15)	(2.59)	(2.10)	(3.55)
Average firm utility for state-owned firms	83.29***	108.77***	106.47***	125.50***
	(0.04)	(0.09)	(0.07)	(0.10)

Notes: All values are in units of billion Yuan. Welfare is calculated using parameter estimates from Specification (2) of Table 2. Standard errors are reported in parentheses. Significance codes: * p<0.05; ** p<0.01; ***p<0.001

Table A3a. Costs based on actual and model predicted data, 2013

	Statistics based on:	
	Actual data	**Model predicted data**
Mean marginal cost (1000 Yuan) for alternative vehicles	1653.80***	1510.90***
	(193.45)	(205.59)
Mean marginal cost (1000 Yuan) for each quartile of fuel efficiency		
1st quartile	269.46***	314.82***
	(0.14)	(41.23)
median	135.29***	132.83***
	(0.13)	(17.77)
3rd quartile	680.61***	578.41***
	(80.19)	(123.17)
4th quartile	39.83***	34.70***
	(0.10)	(7.34)
Mean marginal cost (1000 Yuan) for all cars	213.32***	212.26***
	(7.64)	(38.47)

Notes: Marginal costs are calculated using parameter estimates from Specification (1) of Table 2. Standard errors are reported in parentheses. Significance codes: * $p<0.05$; ** $p<0.01$; *** $p<0.001$

Table A3b. Markups based on actual and model predicted data, 2013

	Statistics based on:	
	Actual data	Model predicted data
Mean markups (1000 Yuan) for alternative vehicles	405.21***	553.19**
	(193.45)	(193.00)
Mean markups (1000 Yuan) for each quartile of fuel efficiency		
1st quartile	271.29***	271.33***
	(0.14)	(0.17)
median	137.2***	137.36**
	(0.13)	(0.14)
3rd quartile	163.87***	223.52***
	(80.19)	(80.08)
4th quartile	41.76***	41.98***
	(0.10)	(0.10)
Mean markups (1000 Yuan) for all cars	165.49***	171.51***
	(7.64)	(7.62)

Notes: Markups are calculated using parameter estimates from Specification (1) of Table 2. Standard errors are reported in parentheses. Significance codes: * p<0.05; ** p<0.01; ***p<0.001

Table A3c. Welfare based on actual and model predicted data, 2013

	Statistics based on:	
	Actual data	**Model predicted data**
Consumer surplus	0.0026***	0.0024***
	(0.0001)	(0.0002)
Total firm profit for private firms	1944.60***	2119.10***
	(0.22)	(189.05)
Average firm profit for private firms	216.07***	235.46***
	(0.03)	(21.01)
Total firm utility for state-owned firms	4156.60***	4159.60***
	(11.22)	(589.79)
Average firm utility for state-owned firms	115.46***	115.54***
	(0.31)	(16.38)

Notes: All values are in units of billion Yuan. Welfare is calculated using parameter estimates from Specification (1) of Table 2. Standard errors are reported in parentheses. Significance codes: * p<0.05; ** p<0.01; ***p<0.001

Table A4. Results with and without random coefficients, 2010-2013

	(1)	(3)
Mean β of marginal utility of:		
Alternative vehicle (dummy)	0.106***	0.105***
	(0.001)	(0.000)
Fuel efficiency (100km/L)	0.235***	0.234***
	(0.002)	(0.000)
Length (m)	0.294***	0.293***
	(0.004)	(0.000)
Weight (metric ton)	0.281***	0.280***
	(0.001)	(0.000)
Capacity (number of seats)	-0.133***	0.134***
	(0.002)	(0.000)
Horsepower (PS)	0.168***	0.167***
	(0.005)	(0.000)
Constant	0.333***	0.332***
	(0.000)	(0.000)
Standard deviation σ of marginal utility of:		
Alternative vehicle (dummy)	0.163***	
	(0.003)	
Fuel efficiency (100km/L)	0.112***	
	(0.001)	
Length (m)	-0.009	
	(0.007)	
Weight (metric ton)	0.347***	
	(0.004)	
Capacity (number of seats)	0.105***	
	(0.000)	
Horsepower (0.01PS)	0.029***	
	(0.001)	
Constant	0.210***	
	(0.002)	
Parameter α in marginal disutility of price (1,000 Yuan)	0.420***	0.419***
	(0.000)	(0.000)
Coefficient γ in marginal cost on:		
Alternative vehicle (dummy)	0.139***	0.138***
	(0.003)	(0.000)
Fuel efficiency (100km/L)	0.060***	0.059***
	(0.000)	(0.000)
Length (m)	0.126***	0.125***
	(0.003)	(0.000)
Weight (metric ton)	0.101***	0.100***
	(0.003)	(0.000)
Capacity (number of seats)	0.156***	0.155***
	(0.002)	(0.000)

Horsepower (0.01PS)	0.113***	0.112***
	(0.003)	(0.000)
State-owned (dummy)	0.111***	0.110***
	(0.005)	(0.000)
Constant	0.245***	0.244***
	(0.006)	(0.000)
Coefficient η in marginal cost on quantity	0.007***	0.006**
	(0.000)	(0.002)
Coefficient Γ in marginal cost on joint venture with:		
Mazda	0.158***	-0.311***
	(0.000)	(0.000)
Honda	-0.064***	0.923***
	(0.006)	(0.000)
Daihatsu	0.054***	0.430***
	(0.004)	(0.000)
Toyota	0.219***	0.185***
	(0.004)	(0.000)
Suzuki	-0.028***	-0.905***
	(0.005)	(0.000)
Nissan	0.033***	0.980***
	(0.000)	(0.000)
Mitsubishi	0.185***	-0.439***
	(0.000)	(0.000)
Isuzu	-0.110***	0.111***
	(0.007)	(0.000)
Daimler	-0.224***	-0.258***
	(0.002)	(0.000)
BMW	-0.059***	0.409***
	(0.001)	(0.000)
Volkswagen	0.035***	0.595***
	(0.000)	(0.000)
Audi	0.092***	0.262***
	(0.007)	(0.000)
Lotus	-0.253***	-0.603***
	(0.004)	(0.000)
GM	-0.189***	0.711***
	(0.005)	(0.000)
Ford	0.029***	0.222***
	(0.003)	(0.000)
Chrysler	-0.135***	-0.117***
	(0.006)	(0.000)
Hyundai	0.003	-0.297***
	(0.008)	(0.000)
Kia	-0.115***	-0.319***
	(0.001)	(0.000)
Volvo	0.134***	-0.424***
	(0.001)	(0.000)
Saab	0.193***	0.508***
	(0.001)	(0.000)
PSA	-0.31***	-0.086***
	(0.001)	(0.000)

Fiat	-0.382***	-0.262***
	(0.000)	(0.000)
Coefficients in marginal cost on international joint venture-technology interactions:		
Has international joint venture * alternative vehicle	0.144***	-0.590***
	(0.001)	(0.000)
Has international joint venture * fuel efficiency	-0.160***	-0.339***
	(0.005)	(0.000)
Has international joint venture * horsepower	-0.073***	-0.650***
	(0.003)	(0.000)
Coefficients in marginal cost on international joint venture country-technology interactions:		
Japan * alternative vehicle	-0.420***	0.112***
	(0.003)	(0.000)
Japan * fuel efficiency	-0.713***	0.534***
	(0.003)	(0.000)
Japan * horsepower	-0.851***	0.090***
	(0.002)	(0.000)
Germany * alternative vehicle	0.118***	-0.495***
	(0.001)	(0.000)
Germany * fuel efficiency	0.708***	0.136***
	(0.002)	(0.000)
Germany * horsepower	0.774***	0.679***
	(0.005)	(0.000)
Britain * alternative vehicle	1.005***	-0.148***
	(0.002)	(0.000)
Britain * fuel efficiency	0.213***	0.190***
	(0.003)	(0.000)
Britain * horsepower	0.615***	-0.495***
	(0.003)	(0.000)
U.S. * alternative vehicle	-0.203***	-0.561***
	(0.002)	(0.000)
U.S. * fuel efficiency	-0.149***	-0.055***
	(0.009)	(0.000)
U.S. * horsepower	-0.662***	-0.851***
	(0.002)	(0.000)
South Korea * alternative vehicle	0.445***	0.583***
	(0.002)	(0.000)
South Korea * fuel efficiency	0.678***	0.930***
	(0.002)	(0.000)
South Korea * horsepower	0.361***	-0.697***
	(0.001)	(0.000)
Sweden * alternative vehicle	0.981***	0.989***
	(0.004)	(0.000)
Sweden * fuel efficiency	0.748***	-0.815***
	(0.002)	(0.000)

Sweden * horsepower	0.912***	-0.879***
	(0.001)	(0.000)
France * alternative vehicle	0.268***	-0.613***
	(0.010)	(0.000)
France * fuel efficiency	0.437***	0.001***
	(0.002)	(0.000)
France * horsepower	0.203***	0.865***
	(0.000)	(0.000)
Italy * alternative vehicle	0.098***	-0.480***
	(0.002)	(0.000)
Italy * fuel efficiency	0.336***	-0.990***
	(0.002)	(0.000)
Italy * horsepower	1.042***	0.528***
	(0.000)	(0.000)
Coefficients in marginal cost on fuel efficiency policy variables:		
Difference between fuel economy target and actual fuel efficiency (100km/L)	0.279***	0.333***
	(0.003)	(0.000)
Corporate Average Fuel Consumption (CAFC) policy is in effect (dummy)	0.547***	0.467***
	(0.004)	(0.000)
CAFC policy dummy * Difference between Corporate Average Fuel Consumption (CAFC) target and actual fuel efficiency (100km/L)	0.958***	0.648***
	(0.006)	(0.000)
Weights on objectives in state-owned firms' utility:		
ρ_1 weight on profit	0.920***	0.600***
	(0.002)	(0.000)
ρ_2 weight on consumer surplus	0.060***	0.300***
	(0.000)	(0.000)
$(1-\rho_1-\rho_2)$ weight on alternative vehicle production	0.020***	0.100***
	(0.002)	(0.000)
Parameters in alternative vehicle production objective in state-owned firms' utility:		
λ_1 weight on quadratic term in alternative vehicle production objective	0.050	0.100
	(0.544)	(141.617)
λ_2 constant in quadratic term in alternative vehicle production objective	150***	600.000***
	(0.000)	(0.000)
# Observations	2,215	2,215

Notes: Standard errors are reported in parentheses. Specification (1) is the base-case random coefficients model Specification (1) from Table 2. Specification (3) is the analogous traditional logit model without any interaction between consumer characteristics and product characteristics. Significance codes: * p<0.05; ** p<0.01; ***p<0.001.

Table A5. Results with and without coefficient on inverse income in marginal disutility of price, 2010-2013

	(1)	(4)
Mean β of marginal utility of:		
Alternative vehicle (dummy)	0.106***	0.106***
Fuel efficiency (100km/L)	0.235***	0.235***
Length (m)	0.294***	0.294***
Weight (metric ton)	0.281***	0.281***
Capacity (number of seats)	-0.133***	-0.133***
Horsepower (PS)	0.168***	0.168***
Constant	0.333***	0.333***
Standard deviation σ of marginal utility of:		
Alternative vehicle (dummy)	0.163***	0.163***
Fuel efficiency (100km/L)	0.112***	0.112***
Length (m)	-0.009	-0.009
Weight (metric ton)	0.347***	0.347***
Capacity (number of seats)	0.105***	0.105***
Horsepower (0.01PS)	0.029***	0.029***
Constant	0.210***	0.210***
Parameters in marginal disutility of price (1,000 Yuan):		
α constant	0.420***	0.420***
α_y coefficient on inverse per capita income (Yuan) $1/y_i$		1.000***
Coefficient γ in marginal cost on:		
Alternative vehicle (dummy)	0.139***	0.139***
Fuel efficiency (100km/L)	0.060***	0.060***
Length (m)	0.126***	0.126***
Weight (metric ton)	0.101***	0.101***
Capacity (number of seats)	0.156***	0.156***
Horsepower (0.01PS)	0.113***	0.113***
State-owned (dummy)	0.111***	0.111***
Constant	0.245***	0.245***
Coefficient η in marginal cost on quantity	0.007***	0.007***
Coefficient Γ in marginal cost on joint venture with:		
Mazda	0.158***	0.158***
Honda	-0.064***	-0.064***
Daihatsu	0.054***	0.054***
Toyota	0.219***	0.219***
Suzuki	-0.028***	-0.028***
Nissan	0.033***	0.033***

Mitsubishi	0.185***	0.185***
Isuzu	-0.110***	-0.110***
Daimler	-0.224***	-0.224***
BMW	-0.059***	-0.059***
Volkswagen	0.035***	0.035***
Audi	0.092***	0.092***
Lotus	-0.253***	-0.253***
GM	-0.189***	-0.189***
Ford	0.029***	0.029***
Chrysler	-0.135***	-0.135***
Hyundai	0.003	0.003
Kia	-0.115***	-0.115***
Volvo	0.134***	0.134***
Saab	0.193***	0.193***
PSA	-0.31***	-0.31***
Fiat	-0.382***	-0.382***
Coefficients in marginal cost on international joint venture-technology interactions:		
Has international joint venture * alternative vehicle	0.144***	0.144***
Has international joint venture * fuel efficiency	-0.160***	-0.160***
Has international joint venture * horsepower	-0.073***	-0.073***
Coefficients in marginal cost on international joint venture country-technology interactions:		
Japan * alternative vehicle	-0.420***	-0.420***
Japan * fuel efficiency	-0.713***	-0.713***
Japan * horsepower	-0.851***	-0.851***
Germany * alternative vehicle	0.118***	0.118***
Germany * fuel efficiency	0.708***	0.708***
Germany * horsepower	0.774***	0.774***
Britain * alternative vehicle	1.005***	1.005***
Britain * fuel efficiency	0.213***	0.213***
Britain * horsepower	0.615***	0.615***
U.S. * alternative vehicle	-0.203***	-0.203***
U.S. * fuel efficiency	-0.149***	-0.149***
U.S. * horsepower	-0.662***	-0.662***
South Korea * alternative vehicle	0.445***	0.445***
South Korea * fuel efficiency	0.678***	0.678***
South Korea * horsepower	0.361***	0.361***
Sweden * alternative vehicle	0.981***	0.981***
Sweden * fuel efficiency	0.748***	0.748***
Sweden * horsepower	0.912***	0.912***
France * alternative vehicle	0.268***	0.268***
France * fuel efficiency	0.437***	0.437***
France * horsepower	0.203***	0.203***

Italy * alternative vehicle	0.098***	0.098***
Italy * fuel efficiency	0.336***	0.336***
Italy * horsepower	1.042***	1.042***
Coefficients in marginal cost on fuel efficiency policy variables:		
Difference between fuel economy target and actual fuel efficiency (100km/L)	0.279***	0.279***
Corporate Average Fuel Consumption (CAFC) policy is in effect (dummy)	0.547***	0.547***
CAFC policy dummy * Difference between Corporate Average Fuel Consumption (CAFC) target and actual fuel efficiency (100km/L)	0.958***	0.958***
Weights on objectives in state-owned firms' utility:		
ρ_1 weight on profit	0.920***	0.920***
ρ_2 weight on consumer surplus	0.060***	0.060***
$(1-\rho_1-\rho_2)$ weight on alternative vehicle production	0.020***	0.020***
Parameters in alternative vehicle production objective in state-owned firms' utility:		
λ_1 weight on quadratic term in alternative vehicle production objective	0.050	0.050
λ_2 constant in quadratic term in alternative vehicle production objective	150***	150***
# Observations	2,215	2,215

Notes: Specification (1) is the base-case Specification (1) from Table 2. Specification (4) estimates the coefficient α_y on inverse per capita income α_y in the marginal disutility of price instead of fixing it at $\alpha_y = 1$. Significance codes: * p<0.05; ** p<0.01; ***p<0.001.