Alternative Vehicle Supply and Demand in the Chinese Automobile Market[1]

Yuan Chen and C.-Y. Cynthia Lin Lawell

Abstract

We analyze alternative vehicle supply and demand, and the effects of introducing a new alternative vehicle in the Chinese automobile market on alternative vehicle market share, consumer surplus, private firm profit, and state-owned firm utility. We use a structural econometric model of a mixed oligopolistic differentiated products market that we have developed and estimated of supply and demand in the Chinese automobile market in order to simulate the effects of introducing a new alternative vehicle to the existing fleet. Results show that introducing a new alternative vehicle does not have significant benefits in terms of either alternative vehicle market share or consumer surplus in any of the counterfactual new alternative vehicle scenarios we simulate. If the new alternative vehicle is introduced by a state-owned firm and does not have high horsepower, then private firms may benefit. Introducing a new alternative vehicle to the existing fleet generally does not yield benefits for the firm that introduces the new alternative vehicle, however. Nevertheless, results point to a possible profitable opportunity from introducing a new alternative vehicle with high horsepower to the Chinese automobile market.

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[1] Chen: Shanghai University of International Business and Economics; yuanchen_suibe@163.com. Lin Lawell: Cornell University; clinlawell@cornell.edu. We are indebted to Erich Muehlegger and Jim Wilen for their mentorship, support, and encouragement throughout this project. We thank Erich Muehlegger, Jim Wilen, Lance Atkins (Nissan Motor Company), Michael Babcock, Panle Jia Barwick, Arie Beresteanu, Jim Bushnell, Michael Canes, Lourdes Casanova, Rajesh Chandy, Robert Crandall, John DeCicco, Aureo de Paula, Isis Durrmeyer, Yueyue Fan, Lew Fulton, Andrea Galeotti, Hamed Ghoddusi, Ben Handel, Stefan Hoderlein, Wuyang Hu, Mark Jacobsen, Timothy Johnson (Corning, Incorporated), Marianne Kah, Shachar Kariv, Doug Kelbaugh, Khaled Kheiravar, Harim Kim, Christina Korting, Shanjun Li, Zhenhong Lin, Lorenzo Magnolfi, Clay Maranville (Ford Motor Company), Patrick McCarthy, Shaun McRae, Andres Mendez Ruiz, Heloisa Menezes, Joan Ogden, Avralt-Od Purevjev, John O'Trakoun (Ford Motor Company), Jing Qian, Yueming (Lucy) Qiu, Vithala Rao, Kyle Redies, Irvin Rojas, Stephen Ryan, Marc Rysman, John Rust, Jim Sallee, Alberto Salvo, Louis Sears, Ashish Sen, Brian Shin, Holger Sieg, Dan Sperling, Lang Sui (Aramco Services Company), James Sweeney, Chad Syverson, Arthur van Benthem, Yunshi Wang, Andrew Waxman, Jeremy Weber, Clifford Winston, C.K. Woo, Junji Xiao, Jianwei Xing, Jia Yan, Hangjun Yang, Xiaohua Yu, Saleh Zakerinia, Anming Zhang, Junjie Zhang, and Martin Zimmerman for helpful comments and discussions. We also benefited from comments from seminar participants at UC-Davis Sustainable Transportation Energy Pathways research seminars, at Renmin University, and at Cornell University; and conference participants at the Brookings Tsinghua Center Conference; the Asian Meeting of the Econometric Society; the China Meeting of the Econometric Society; the Conference on Transportation, Economics, Energy, and the Environment (TE3) at the University of Michigan; the U.S. Association for Energy Economics North American Conference; the Transportation Research Forum Annual Conference; an Association of Environmental and Resource Economists (AERE) session at the Southern Economic Association Annual Conference; the International Association for Energy Economics (IAEE) Asian Conference; the Joint Cornell Institute for China Economic Research (CICER) and Emerging Markets Institute (EMI) Emerging Markets Research Day; the International Industrial Organization Conference; the Interdisciplinary Ph.D. Workshop in Sustainable Development at Columbia University; the Agricultural and Applied Economics Association Annual Meeting; a Transportation and Public Utilities Group (TPUG) session at the Western Economic Association International (WEAI) Annual Conference; the University of California at Davis Sustainable Transportation Energy Pathways Symposium; and the 3rd South Lake Innovation Forum for International Young Talents at Huazhong Agricultural University. We are grateful to Xinbiao Gu for helping us collect the data. We received financial support from a National Center for Sustainable Transportation Dissertation Grant, a Nissan ITS-Davis Corporate Affiliate Fellowship, the UC-Davis Institute of Transportation Studies China Center for Energy and Transportation, an ITS-Davis Travel Grant, an UC-Davis Graduate Student Travel Award, an Agricultural and Applied Economics Association Travel Grant, a U.S. Association for Energy Economics Conference Registration Fee Scholarship, an UC-Davis Transportation Technology and Policy Fellowship, and a Shell ITS-Davis Corporate Affiliate Fellowship. Lin Lawell is a Faculty Fellow at the Atkinson Center for a Sustainable Future. All errors are our own.

1. Introduction

China's automobile market is the largest in the world, having surpassed the U.S. automobile market both in sales and production in 2009. The annual gross product of the Chinese automobile industry has exceeded 5% of the country's annual GDP every year since 2002, and was as high as 7.4% of its GDP in 2010 (Chen, Lin Lawell and Wang, 2020).[2] This rapid increase in vehicle ownership and vehicle usage is associated with issues such as local air pollution and global climate change (Du et al., 2009; Lin and Zeng, 2014), as well as a concomitant interest in alternative vehicles that are powered by alternative fuel sources other than gasoline or diesel (Chen, Lin Lawell and Wang, 2020).[3]

The business benefits of producing alternative vehicles are unclear, especially in emerging and transition economies such as China where environmental and social regulations may be lacking or poorly enforced, and where the demand for greener products may be virtually non-existent (Blackman, 2010; Earnhart, Khanna and Lyon, 2014). In addition, the Chinese central government is often torn between a desire to strengthen environmental protection on the one hand, and a fear of taking any action that might reduce GDP growth rates on the other (Li, 2012; Lyon et al., 2013).

In this paper, we analyze alternative vehicle supply and demand, and the effects of introducing a new alternative vehicle in the Chinese automobile market. To do so, we use a structural econometric model of a mixed oligopolistic differentiated products market of supply and demand in the Chinese automobile market that we developed and estimated in Chen and Lin Lawell (2021b). Our model was estimated using a comprehensive data set on the sales, prices, and characteristics of the majority of vehicle makes and models in China, including alternative 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. 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.

[2] These statistics were calculated using GDP data from the National Bureau of Statistics of China and automobile industry gross product data from Chinese Automobile Industry Yearbook.

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

We use our model from Chen and Lin Lawell (2021b) to simulate the effects of introducing a counterfactual new alternative vehicle to the existing fleet on alternative vehicle market share and welfare. Results show that introducing a new alternative vehicle does not have significant benefits in terms of either the number of alternative vehicles purchased or consumer surplus in any of the counterfactual new alternative vehicle scenarios we simulate. If the new alternative vehicle is introduced by a state-owned firm and does not have high horsepower, then private firms may benefit.

We find that introducing a new alternative vehicle to the existing fleet generally does not yield benefits for the firm that introduces the new alternative vehicle. One exception is that the state-owned Chinese automobile company that produces the Buick E-assist 2.4L hybrid (Shanghai Automotive Industry Corporation, in its international joint venture with General Motors) would benefit from also producing a new car that has all the same characteristics as the Buick E-assist 2.4L hybrid except with horsepower 25% higher. Our results suggest that introducing a new alternative vehicle with high horsepower to the Chinese automobile market may be a possible profitable opportunity.

The balance of our paper proceeds as follows. We review the literature in Section 2. Section 3 describes our econometric model from Chen and Lin Lawell (2021b). We describe the data from Chen and Lin Lawell (2021b) in Section 4. Section 5 analyzes demand elasticities. Our counterfactual simulations and their results are described in Section 6. Section 7 discusses our results and concludes.

2. Literature Review

2.1. Vehicle demand and supply

The first strand of literature upon which we build is that on vehicle demand and supply, particularly for alternative vehicles. There is a burgeoning literature on vehicle demand (see e.g., Adjemian, Lin and Williams, 2010; Sallee, West and Fan, 2016; Anderson and Sallee, 2016; Archsmith et al. 2017; Filippini and Wekhof, 2017), including the demand for alternative vehicles (Hidrue et al., 2011; Heutel and Muehlegger, 2015; Holland, Mansur, Muller, and Yates, 2016; Sheldon, DeShazo and Carson; 2016; Li, Lang, Xing, and Zhou, 2017; Zhou and Li, 2018) and the effects of government policy on vehicle demand, particularly for alternative vehicles (Gallagher and Muehlegger, 2011; Beresteanu and Li, 2011; Sallee, 2011; Li, Linn and Spiller, 2013; Hoekstra, Puller and West, 2017; Sheldon and DeShazo, 2017; DeShazo, Sheldon and Carson, 2017; Muehlegger and Rapson, 2019; Dorsey, Langer and McRae, 2019). Axsen, Bailey and Castro (2015) find that car buyers exhibit high degrees of heterogeneity in both preferences and motivations.

The literature on vehicle markets and policy also includes studies of vehicle supply, and the effects of policies on vehicle supply and manufacturer incentives, including for alternative vehicles (Ullman, 2016; Miravete, Moral and Thurk, 2018; Shao, Yang and Zhang, 2019). A related literature studies the costs and benefits of alternative vehicles on the eletric grid, emissions, and energy consumption (Lyon et al., 2012; Graff Zivin, Kotchen and Mansur, 2014; Gillingham, Rapson and Wagner, 2016).

The literature on vehicle markets and policy also includes studies of government policies related to vehicles (Greene, 1991; Goldberg, 1998; Kleit, 2004; Austin and Dinan, 2005; Bento et al., 2009; Chen, Esteban and Shum, 2010; Anderson and Sallee, 2011; Knittel, 2011; Klier and Linn, 2012; Jacobsen and van Benthem, 2015; Sallee and Slemrod, 2012; Jacobsen, 2013; Bento, Gillingham and Roth, 2017; Leard, Linn and McConnell, 2017; Kellogg, 2018; Ito and Sallee, 2018; Bento et al., 2018; Durrmeyer and Samano, 2018; Levinson, 2019; Huse and Koptyug, 2019; Davis and Knittel, 2019; Bento et al., 2020).

2.2. Vehicle markets and policy in China

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

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. Nienhueser and Qiu (2016) analyze the impacts of providing renewable energy for electric vehicle charging. 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. Woo et al. (2008) and Cao et al. (2020) study license plate auctions in Hong Kong. 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. Chen, Hu and Knittel (2021) find that China's subsidy program for fuel efficient vehicles boosted sales for subsidized vehicle models, but also created a substitution effect within highly fuel efficient vehicles that greatly reduces the cost-effectiveness of the program. Using data from the US and China, DeCicco (2013) finds that beyond fundamental R&D, policies to commercialize alternative vehicles are not necessarily required for climate protection.

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.

In terms of factors affecting vehicle demand in China, Lin and Zeng (2013) estimate the price and income elasticities of demand for gasoline and the vehicle miles traveled (VMT) elasticity in China. In their analysis of brand name types and consumer demand, Wu et al. (2019) find that Chinese consumers prefer vehicle models with semantic brand names rather than alphanumeric, phonetic, or phonosemantic brand names. 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 (forthcoming) 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.

3. Structural Model of Chinese Automobile Market

We use the random coefficients mixed oligopolistic differentiated products model of the Chinese automobile market that we have developed and estimated in Chen and Lin Lawell (2021b). This model 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.

On the demand side, our model in Chen and Lin Lawell (2021b) uses 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.

In a random coefficients demand model, owing to the interactions between consumer preferences and product characteristics, 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[4] and observed product characteristics, our random coefficients model of vehicle demand generates reasonable substitution patterns.

According to the results in Chen and Lin Lawell (2021b), 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.

On the supply side, our model in Chen and Lin Lawell (2021b) innovates 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 maximizes the joint profits over all vehicle models that the firm produces. 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, consumer surplus, and alternative vehicle production.

[4] 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.

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.[5] 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 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. 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

[5] It is possible that the Chinese central government may care about the utilities of all its consumers. 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 its 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.

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). Alternative vehicles are only produced by state-owned firms during the time period of our analysis.

Our parameter estimates in Chen and Lin Lawell (2021b) show that state-owned car companies may have different objectives from private car companies. Results show, however, that the majority of the weight (92%) is on profit, with some weight on consumer surplus (6%) and a little weight on alternative vehicle production (2%). Thus, although state-owned car companies care about other objectives such as consumer surplus and alternative vehicle production, their primary objective is to make profits.

To examine whether joint ventures between Chinese automobile companies and different international car companies have different marginal costs, our model in Chen and Lin Lawell (2021b) includes dummies for joint ventures with each international car company in the specification of marginal costs. To examine whether Chinese automobile companies that form joint ventures with international car companies have better technology, our specification for marginal cost includes interactions between the international joint venture dummy with some of the technology-related car characteristics. 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 also includes interactions between an international joint venture country dummy and technology-related vehicle characteristics.

The parameter estimates in Chen and Lin Lawell (2021b) 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. Moreover, 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.

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, our model in Chen and Lin Lawell (2021b) includes three fuel efficiency policy interaction terms in the marginal cost.

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.

According to the results in Chen and Lin Lawell (2021b), 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.

For more details on our random coefficients mixed oligopolistic differentiated products model of the Chinese automobile market that we have developed and estimated in Chen and Lin Lawell (2021b), including details about the demand model, supply model, instruments, estimation, identification, parameter estimates, model validation, and welfare results, see Chen and Lin Lawell (2021b).

4. Data

Our model in Chen and Lin Lawell (2021b) is estimated using 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 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.[6] 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.*

[6] 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*

Unlike in the U.S. and France,[7] 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, forthcoming). 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, forthcoming), 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.

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

[7] 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.

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 1 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.

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 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. Demand Elasticities

We use the parameter estimates in Chen and Lin Lawell (2021b) to calculate the own- and cross-price elasticities of demand for 20 different vehicle models. Own-price elasticities $\frac{\partial s_j}{\partial p_j}\frac{p_j}{s_j}$

and cross-price elasticities $\frac{\partial s_j}{\partial p_k}\frac{p_k}{s_j}$ for each of the 20 different vehicle models *j* are calculated by taking the respective derivatives of the market share equation (6) in Chen and Lin Lawell (2021b), where the expectation in the derivative is taken over the distribution of income y_i.

As seen in the own-price elasticities in Table 2, the demand for each of 20 different vehicle models is highly elastic. The absolute value of the own-price elasticities are larger for the Honda CR-V 2.4L, the Tiguan 1.8, and the ix35 2.0L, all of which are produced by international joint ventures.

To examine whether alternative vehicles are considered substitutes to vehicles fueled by gasoline or diesel, we use the parameter estimates in Chen and Lin Lawell (2021b) to calculate the cross-price elasticities of the demand for each of the 20 different vehicle models *j* with respect to the price of a particular alternative vehicle model *k*: the Buick E-assist 2.4L hybrid. The 20 different vehicle models *j* we use are the same 20 vehicle models *j* for which we calculate own-price elasticities. As seen in Table 2, for each of the 20 different vehicle models *j*, the cross-price elasticity of demand for that vehicle model *j* with respect to the price of the Buick E-assist 2.4L hybrid is zero. Thus, none of the 20 different vehicle models are substitutes for the Buick E-assist 2.4L hybrid.

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 in Chen and Lin Lawell (2021b) to run counterfactual simulations to analyze the effects on demand, cost, and welfare of introducing a new alternative vehicle.

Each new alternative vehicle scenario we simulate involves the introduction of a new alternative vehicle that is similar to the Buick E-assist 2.4L hybrid, an alternative vehicle that is produced by a state-owned Chinese automobile company that has an international joint venture. More specifically, the Buick E-assist 2.4L hybrid is produced by a joint venture between the state-owned Chinese automobile company Shanghai Automotive Industry Corporation and the international car company General Motors. For each new alternative vehicle scenario, we introduce a new alternative vehicle that is similar to the Buick E-assist 2.4L hybrid, save for one characteristic.

In particular, we simulate introducing a new car that has all the same characteristics as the Buick E-assist 2.4L hybrid, except: (1) its fuel efficiency is 25% more fuel efficient, (2) its length is 25% times longer, (3) its weight is 25% heavier, (4) its weight is 25% lighter, (5) it has one more seat, (6) its horsepower is 25% higher, (7) its horsepower is 25% lower, (8) the state-owned firm that produces it does not have an international joint venture, (9) it is produced by a private firm that has an international joint venture, or (10) it is produced by a private firm without an international joint venture.

For each counterfactual scenario, we analyze the effects of introducing the counterfactual new alternative vehicle to the existing fleet in 2013 on demand, cost, and welfare. To do so, we calculate statistics for market shares, costs, and welfare in 2013 for each counterfactual scenario we simulate. 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 with the addition of a new alternative vehicle, at least in the short run. Similarly, it seems reasonable to assume that parameters in marginal costs would not change with the addition of a new alternative vehicle, 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 with the addition of a new alternative vehicle, at least in the short run. If anything, the decision to add a new alternative vehicle might be induced by parameters in consumer utility, firm costs, and/or the objectives of state-owned firms, rather than the other way around.

In our counterfactual new car scenarios, we take the vehicle characteristics of vehicles in the existing fleet as given, but allow all firms to adjust the prices of all their cars in response to the introduction of the new car. We are therefore simulating an unexpected introduction of a new alternative vehicle in the market by one firm that other firms did not anticipate in time to enable them to respond by changing the set of vehicles they were producing that year and/or the characteristics of the vehicles they were producing that year.

For each new car 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 Table 3, which 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.

As seen in Table 3, none of the new alternative vehicle scenarios we simulate leads to a significant change from the status quo base case in either the alternative vehicle market share, the consumer surplus, or the average utility of state-owned firms. In addition, none of the new alternative vehicle scenarios we simulate leads to a significant change from the status quo base case in the mean marginal cost for alternative vehicles, or in the mean marginal costs for all cars (not shown).

We find that average firm profit for private firms increases for all the new alternative vehicle scenarios with the exception of the scenario in which the new car introduced has horsepower 25% higher, and the scenarios in which the new car is produced by a private firm. Since in most scenarios the new car is being produced by a state-owned firm, this means that, in the scenarios in which the new car is introduced by a state-owned firm and does not have higher horsepower than the Buick E-assist 2.4L hybrid, average firm profit for private firms increases. This also means that if the new car is produced by a private firm, there is no significant change at a 5% level in the average firm profit for private firms, whether or not the private firm producing the new alternative vehicle has an international joint venture.

As seen in Table 3, the utility of the firm producing the new car -- summed over all cars that it produces, including all the existing cars that the firm produces, and therefore accounting for the effects of this new car on the market shares of all the other cars the firm produces -- increases if the new car introduced has all the same characteristics as the Buick E-assist 2.4L hybrid except its horsepower is 25% higher. This suggests that the state-owned Chinese automobile company that produces the Buick E-assist 2.4L hybrid (Shanghai Automotive Industry Corporation, in its international joint venture with General Motors) would benefit from also producing a new car that has all the same characteristics as the Buick E-assist 2.4L hybrid except with horsepower 25% higher. In the other new car scenarios we simulate, however, introducing the counterfactual new alternative vehicle to the existing fleet does not have a significant effect at a 5% level on the utility of the firm producing the new alternative vehicle.

7. Discussion and Conclusion

In this paper, we analyze alternative vehicle supply and demand, and the effects of introducing a new alternative vehicle in the Chinese automobile market. To do so, we use a structural econometric model of a mixed oligopolistic differentiated products market of supply and demand in the Chinese automobile market that we developed and estimated in Chen and Lin Lawell (2021b). Our model 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 was estimated using a comprehensive data set on the sales, prices, and characteristics of the majority of vehicle makes and models in China, including alternative 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. 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 use our model from Chen and Lin Lawell (2021b) to simulate the effects of introducing a counterfactual new alternative vehicle to the existing fleet on alternative vehicle market share and welfare. Our counterfactual new car scenarios yield several main results. First, none of the new alternative vehicle scenarios we simulate leads to a significant change from the status quo base case in either the alternative vehicle market share, the consumer surplus, or the average utility of state-owned firms. Thus, introducing a new alternative vehicle does not have significant benefits in terms of either the number of alternative vehicles purchased or consumer surplus in any of the new alternative vehicle scenarios we simulated.

A second main result of our new alternative vehicle scenarios is that average firm profit for private firms increases when the new car is being produced by a state-owned firm and does not have higher horsepower than the Buick E-assist 2.4L hybrid. Thus, private firms may benefit if a state-owned firm introduces a new alternative vehicle that does not have high horsepower.

A third main result is that if the new car is instead produced by a private firm, there is no significant change in the average firm profit for private firms, whether or not the private firm producing the new alternative vehicle has an international joint venture. Neither the firm itself nor private firms on average appear to benefit when a private firm introduces a new alternative vehicle. This result is consistent with the finding of Lyon et al. (2013) that market forces provide limited incentive for environmental improvement in China.

A fourth main result is that the state-owned Chinese automobile company that produces the Buick E-assist 2.4L hybrid (Shanghai Automotive Industry Corporation, in its international joint venture with General Motors) would benefit from also producing a new car that has all the same characteristics as the Buick E-assist 2.4L hybrid except with horsepower 25% higher. Thus, our results suggest that, based on consumer preferences, firm costs, state-owned firm objectives, government policy, and the existing fleet in 2013, the international joint venture between Shanghai Automotive Industry Corporation and General Motors may have benefited by introducing the following new alternative vehicle to the existing fleet in 2013, while still producing the cars it was already producing in 2013: a car that has all the same characteristics as the Buick E-assist 2.4L hybrid except with horsepower 25% higher. Our results therefore point to a possible profitable opportunity from introducing a new alternative vehicle with high horsepower to the Chinese automobile market.

A fifth main result is that the firm introducing the new alternative vehicle may not necessarily benefit from doing so. While the state-owned Chinese automobile company that produces the Buick E-assist 2.4L hybrid would benefit from introducing a new car that has all the same characteristics as the Buick E-assist 2.4L hybrid except with horsepower 25% higher, it may not necessarily benefit from instead introducing a new alternative vehicle that differed from the Buick E-assist 2.4L hybrid in other aspects.

Our result that most counterfactual new alternative vehicles we considered would not have been beneficial for a firm to introduce to the existing fleet seems reasonable, and consistent with the observed fleet being the result of firm optimizing behavior. Nevertheless, our results suggest that there may have been a profitable opportunity left on the table from introducing a new alternative vehicle with high horsepower to the Chinese automobile market.

Our results that the introduction of a new alternative vehicle by a state-owned automobile company may potentially benefit either private firms or the state-owned firm itself are consistent with the results of Lyon et al. (2013) that the market does not penalize environmental leadership by state-owned enterprises and that the Chinese central government therefore provides some incentives for environmental protection through exercising the control that comes with ownership.

Our research points to several potential avenues for future research. A first 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 in the existing fleet as given. Our counterfactual new car scenarios simulate an unexpected introduction of a new alternative vehicle in the market by one firm that other firms did not anticipate in time to enable them to respond by changing the set of vehicles they were producing that year and/or the characteristics of the vehicles they were producing that year. It is possible that the vehicle characteristics of cars in the existing fleet would have been different, however, if other firms were able to anticipate the introduction of a new car in time for them to respond by changing their vehicles and vehicle characteristics in addition to changing their vehicle prices. In future work we hope to endogenize the choice of vehicle characteristics as well.

A second 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. Even if rival firms were unable to respond to a new vehicle by changing their vehicles and vehicle characteristics immediately, it is possible that they would respond by changing their vehicles and vehicle characteristics over time in subsequent years. In future work we hope to model the firms' decisions as a dynamic game.

A third potential avenue for future research is to also incorporate the dynamics of the used car market 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 Busse, Knittel and Zettelmeyer (2013), Jacobsen (2013), Bollinger (2015), Gillingham et al. (2016), Bento et al. (2020), and Li, Liu and Wei (2021).

Fourth, 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, forthcoming) and to analyze the effects of any local government policies.

A fifth potential avenue for future research is to include demand-side policies as well as supply-side policies for alternative vehicles. The government policies we include in our model, including fuel economy policies, are primarily supply-side policies. Chen, Hu and Knittel (2021) and Qian (2018) analyze China's subsidies for fuel efficient and electric vehicles. As our national data precludes us from including local subsidies (Qian, 2018), and as the effective date and the duration of the national subsidy for particular fuel efficient vehicle models are not clear to firms or consumers (Chen, Hu and Knittel, 2021), we do not incorporate subsidies in our model. In future work we hope to incorporate, analyze, and compare demand-side policies and supply-side policies and their interactions with each other.

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 (2021a) use the structural econometric model of a mixed oligopolistic differentiated products market developed in Chen and Lin Lawell (2021b) to simulate and analyze the effects of counterfactual fuel efficiency policies on alternative vehicle market share and welfare.

Our research has important implications for industry, government, society, academia, and NGOs. Our research may also be of particular interest to car manufacturers interested in better targeting cars, including alternative vehicles, for the Chinese market.

References

Adjemian, M.K., C.-Y.C. Lin, and J. Williams. (2010). Estimating spatial interdependence in automobile type choice with survey data. Transportation Research Part A: Policy and Practice, 44, 661-675.

Aghion, P., A. Dechezleprêtre, D. Hémous, R. Martin, and J. Van Reenen. (2016). Carbon taxes, path dependency and directed technical change: Evidence from the auto industry. Journal of Political Economy, 124 (1), 1-51.

Anderson, S.T., R. Kellogg, A. Langer, and J.M. Sallee. (2015). The intergenerational transmission of automobile brand preferences. Journal of Industrial Economics, 63 (4), 763-793.

Anderson, S.T., and J.M. Sallee. (2011). Using loopholes to reveal the marginal cost of regulation: The case of fuel-economy standards. American Economic Review, 101 (4), 1375-1409.

Anderson, S.T., and J.M. Sallee. (2016). Designing policies to make cars greener. Annual Review of Resource Economics, 8 (1), 157-180.

Angrist, J., K. Graddy, and G.W. Imbens. (2000). The interpretation of instrumental variables estimators in simultaneous equations models with an application to the demand for fish. Review of Economic Studies, 67 (3), 499-527.

Armstrong, T.B. (2016). Large market asymptotics for differentiated product demand estimators with economic models of supply. Econometrica, 84 (5), 1961-1980.

Austin, D., and T. Dinan. (2005). Clearing the air: The costs and consequences of higher CAFE standards and increased gasoline taxes. Journal of Environmental Economics and Management, 50 (3), 562-582.

Axsen, J., J. Bailey, and M.A. Castro. (2015). Preference and lifestyle heterogeneity among potential plug-in electric vehicle buyers. Energy Economics, 50, 190-201.

Bajari, P., D. Nekipelov, S.P. Ryan, and M. Yang. (2015). Machine learning methods for demand estimation. American Economic Review, 105 (5), 481-485.

Barwick, P.J., S. Cao, and S. Li. (forthcoming). Local protectionism, market structure, and social welfare: China's automobile market. American Economic Journal: Economic Policy.

Bento, A.M., K. Gillingham, M.R. Jacobsen, C.R. Knittel, B. Leard, J. Linn, V. McConnell, D. Rapson, J.M. Sallee, A.A. van Benthem, and K.S. Whitefoot. (2018). Flawed analyses of U.S. auto fuel economy standards. Science, 362 (6419), 1119-1121.

Bento, A., K. Gillingham, and K. Roth. (2017). The effect of fuel economy standards on vehicle weight dispersion and accident fatalities. NBER Working Paper No. 23340.

Bento, A.M., L.H. Goulder, M.R. Jacobsen, and R.H. von Haefen. (2009). Distributional and efficiency impacts of increased US gasoline taxes. American Economic Review, 99 (3), 667-699.

Bento, A.M., M.R. Jacobsen, C.R. Knittel, and A.A. van Benthem. (2020). Estimating the costs and benefits of fuel-economy standards. Environmental and Energy Policy and the Economy, 1, 129-157.

Beresteanu, A., and S. Li. (2011). Gasoline prices, government support, and the demand for hybrid vehicles in the United States. International Economic Review, 52 (1), 161-182.

Berkowitz, D., H. Ma, and S. Nishioka. (2017). Recasting the iron rice bowl: The reform of China’s state owned enterprises. Review of Economics and Statistics, 99 (4), 735-747.

Berry, S. (1994). Estimating discrete choice models of product differentiation. RAND Journal of Economics, 25 (2), 242-262.

Berry, S.T. and P.A. Haile. (2014). Identification in differentiated products markets using market level data. Econometrica, 82 (5), 1749-1797.

Berry, S.T. and P.A. Haile. (2016). Identification in differentiated products markets. Annual Review of Economics, 7 (1), 27-52.

Berry, S., J. Levinsohn, and A. Pakes. (1995). Automobile prices in market equilibrium. Econometrica, 63 (4), 841-890.

Berry, S., J. Levinsohn, and A. Pakes. (2004). Differentiated products demand systems from a combination of micro and macro data: The new car market. Journal of Political Economy, 112 (1), 68-105.

Blackman, A. (2010). Alternative pollution control policies in developing countries. Review of Environmental Economics and Policy, 4, 234-253.

Bollinger, B. (2015). Green technology adoption: An empirical study of the Southern California garment cleaning industry. Quantitative Marketing and Economics, 13(4), 319-358.

Bresnahan, T. (1982). The oligopoly solution concept is identified. Economics Letters, 10, 87-92.

Brown, P.H., E. Bulte, and X. Zhang. (2011). Positional spending and status seeking in rural China. Journal of Development Economics, 96 (1), 139-149.

Busse, M., J. Silva-Risso, and F. Zettelmeyer. (2006). $1,000 cash back: The pass-through of auto manufacturer promotions. American Economic Review, 96 (4), 1253-1270.

Cao, K.H., C.K. Woo, L. Zhang, and Y.X. Zhang. (2020). Willingness to pay for a message: Personalized license plate auctions in Hong Kong. Applied Economics Letters.

Chen, C.-W., W.-M. Hu, and C.R. Knittel. (2021). Subsidizing fuel efficient cars: Evidence from China's automobile industry. American Economic Journal: Economic Policy, forthcoming.

Chen, J., S. Esteban, and M. Shum. (2010). Do sales tax credits stimulate the automobile market? International Journal of Industrial Organization, 28 (4), 397-402.

Chen, Y., and C.-Y.C. Lin Lawell. (2021a). Fuel efficiency policies in the Chinese automobile market: Evidence from a random coefficients mixed oligopolistic differentiated products model. Working paper, Cornell University.

Chen, Y., and C.-Y.C. Lin Lawell. (2021b). Supply and demand in the Chinese automobile market: A random coefficients mixed oligopolistic differentiated products model. Working paper, Cornell University.

Chen, Y., C.-Y.C. Lin Lawell, and Y. Wang. (2020). The Chinese automobile industry and government policy. Research in Transportation Economics, 84, 100849.

Darido, G., M. Torres-Montoya, and S. Mehndiratta. (2014). Urban transport and CO_2 emissions: Some evidence from Chinese cities. Wiley Interdisciplinary Review: Energy and Environment, 3 (2), 122-155.

Davis, L.W., and C.R. Knittel. (2019). Are fuel economy standards regressive? Journal of the Association of Environmental and Resource Economists, 6 (S1), S37-S63.

DeCicco, J.M. (2013). Factoring the car-climate challenge: Insights and implications. Energy Policy, 59, 382-392.

Deng, H., and A. Ma. (2010). Market structure and pricing strategy of China's automobile industry. Journal of Industrial Economics, 58 (4), 818-845.

DeShazo, J.R., T.L. Sheldon, and R.T. Carson. (2017). Designing policy incentives for cleaner technologies: Lessons from California's plug-in electric vehicle rebate program. Journal of Environmental Economics and Management, 84, 18-43.

D'Haultfoeuille, X., I. Durrmeyer, and P. Février. (2019). Automobile prices in market equilibrium with unobserved price discrimination. Review of Economic Studies, 86 (5), 1973-1998.

Dorsey, J., A. Langer, and S. McRae. (2019). Fueling alternatives: Evidence from real-world driving data. Working paper, Indiana University, University of Arizona, and ITAM.

Du, X., L. Fu, Y. Qiu, and T. Jin. (2009). Investigation on vehicular pollution level in various transport micro-environments in Beijing. China Environmental Science, 29 (1), 955-960.

Dube, J.-P., J.T. Fox, and C.-L. Su. (2012). Improving the numerical performance of static and dynamic aggregate discrete choice random coefficients demand estimation. Econometrica, 80 (5), 2231-2267.

Dunker, F., S. Hoderlein, and H. Kaido. (2015). Nonparametric identification of endogenous and heterogeneous aggregate demand models: complements, bundles and the market level. Working paper, Ruhr-Universität Bochum, Boston College, and Boston University.

Durrmeyer, I., and M. Samano. (2018). To rebate or not to rebate: Fuel economy standards vs. feebates? Economic Journal, 128 (616), 3076-3116.

Earnhart, D., M. Khanna, and T.P. Lyon (2014). Corporate environmental strategies in emerging economies. Review of Environmental Economics and Policy, 8, 164-185.

Feenstra, R.C., and J. Levinsohn. (1995). Estimating markups and market conduct with multidimensional product attributes. Review of Economic Studies, 62, 19-52.

Filippini, M., and T.E. Wekhof. (2017). The effect of culture on energy efficient vehicle ownership. CER-ETH Center of Economic Research at ETH Zurich Working Paper No. 17/278.

Gallagher, K.S. and E. Muehlegger. (2011). Giving green to get green?: Incentives and consumer adoption of hybrid vehicle technology. Journal of Environmental Economics and Management, 61, 1-15.

Gillingham, K., D.S. Rapson, and G. Wagner. (2016). The rebound effect and energy efficiency policy. Review of Environmental Economics and Policy, 10 (1), 68-88.

Goldberg, P.K. (1995). Product differentiation and oligopoly in international markets: The case of the U.S. automobile industry. Econometrica, 63 (4), 891-951.

Goldberg, P.K. (1998). The effects of the Corporate Average Fuel Efficiency standards in the US. Journal of Industrial Economics, 46 (1), 1-33.

Goldberger, A.S. (1991). A Course in Econometrics. Cambridge, MA: Harvard University Press.

Graff Zivin, J., M. Kotchen, and E. Mansur. (2014). Temporal and spatial heterogeneity of marginal emissions: Implications for electric cars and other electricity-shifting policies. Journal of Economic Behavior and Organization, 107, 248-268.

Greene, D.L. (1991). Short-run pricing strategies to increase corporate average fuel economy. Economic Inquiry, 29 (1), 101-114.

Hellerstein, R., and S.B. Villas-Boas. (2010). Outsourcing and pass-through. Journal of International Economics, 81 (2), 170-183.

Heutel, G., and E. Muehlegger. (2015). Consumer learning and hybrid vehicle adoption. Environmental and Resource Economics, 62, 125-161.

Hidrue, M.K., G.R. Parsons, W. Kempton, and M.P. Gardner. (2011). Willingness to pay for electric vehicles and their attributes. Resource and Energy Economics, 33 (3), 686-705.

Hoderlein, S., J. Klemela, and E. Mammen. (2010). Analyzing the random coefficient model nonparametrically. Econometric Theory, 26 (3), 804-837.

Hoekstra, M., S.L. Puller, and J. West. (2017). Cash for Corollas: When stimulus reduces spending. American Economic Journal: Applied Economics, 9 (3), 1-35.

Holland, S.P., E.T. Mansur, N.Z. Muller and A.J. Yates. (2016). Are There Environmental Benefits from Driving Electric Vehicles? The Importance of Local Factors. American Economic Review, 106 (12), 3700-3729.

Hu, W.-M., J. Xiao, and X. Zhou. (2014). Collusion or Competition? Interfirm Relationships in the Chinese Auto Industry. Journal of Industrial Economics, 62 (1), 1-40.

Huo, H., M. Wang, L. Johnson, and D. He. (2007). Projection of Chinese Motor Vehicle Growth, Oil Demand, and C02 Emissions through 2050. Transportation Research Record, 2038, 69-77.

Huse, C., and N. Koptyug. (2019). Salience and policy instruments: Evidence from the auto market. Working paper, University of Oldenburg.

Ito, K., and J.M. Sallee. (2018). The economics of attribute-based regulation: Theory and evidence from fuel-economy standards. Review of Economics and Statistics, 100 (2), 319-336.

Jacobsen, M.R. (2013). Evaluating U.S. fuel economy standards in a model with producer and household heterogeneity. American Economic Journal: Economic Policy, 5 (2), 148-187.

Jacobsen, M.R., and A.A. van Benthem (2015). Vehicle scrappage and gasoline policy. American Economic Review, 105 (3), 1312-1328.

Jiang, K., W. Keller, L.D. Qiu, and W. Ridley. (2018). International joint ventures and internal vs. external technology transfer: Evidence from China. NBER Working Paper No. 24455.

Kellogg, R. (2018). Gasoline price uncertainty and the design of fuel economy standards. Journal of Public Economics, 160, 14-32.

Kheiravar, K.H., C.-Y.C. Lin Lawell, and A.M. Jaffe. (2020). The world oil market and OPEC: A structural econometric model. Working paper, Cornell University.

Kleit, A.N. (2004). Impacts of long-range increases in the fuel economy (CAFE) standard. Economic Inquiry, 42 (2), 279-294.

Klier, T., and J. Linn. (2012). New-vehicle characteristics and the cost of the Corporate Average Fuel Economy standard. RAND Journal of Economics, 43 (1), 186–213.

Knittel, C.R. (2012). Automobiles on steroids: Product attribute trade-offs and technological progress in the automobile sector. American Economic Review, 101 (7), 3368-3399.

Knittel, C.R., and K. Metaxoglou. (2014). Estimation of random-coefficient demand models: Two empiricists' perspective. Review of Economics and Statistics, 96 (1), 34-59.

Langer, A. and N. Miller. (2013). Automakers' short-run responses to changing gasoline prices. Review of Economics and Statistics, 95 (4), 1198-1211.

Leard, B., J. Linn, and V. McConnell. (2017). Fuel prices, new vehicle fuel economy, and implications for attribute-based standards. Journal of the Association of Environmental and Resource Economists, 4 (3), 659-700.

Levinson, A. (2019). Energy efficiency standards are more regressive than energy taxes: Theory and evidence. Journal of the Association of Environmental and Resource Economists, 6 (S1), S7-S36.

Li, S. (2018). Better lucky than rich?: Welfare analysis of automobile license allocations in Beijing and Shanghai. Review of Economic Studies, 85 (4), 2389-2428.

Li, S., T. Lang, J. Xing, and Y. Zhou. (2017). The market for electric vehicles: indirect network effect and policy impacts. Journal of the Association of Environmental and Resource Economists, 4 (1), 89-133.

Li, S., J. Linn, and E. Spiller. (2013). Evaluating "Cash-for-Clunkers": Program effects on auto sales and the environment. Journal of Environmental Economics and Management, 65 (2), 165-193.

Li, S., Y. Liu, and C. Wei. (2021). The cost of greening stimulus: A dynamic analysis of vehicle scrappage programs. Working paper, Cornell University.

Li, S., J. Xiao, and Y. Liu. (2015). The price evolution in China's automobile market. Journal of Economics & Management Strategy, 24 (4), 786-810.

Li, W. (2012). Advocating environmental interests in China. Administration and Society, 44 (Suppl.), 26S-42S.

Lin, C.-Y.C. (2011). Estimating supply and demand in the world oil market. Journal of Energy and Development, 34 (1), 1-32.

Lin, C.-Y.C., and L. Prince. (2009). The optimal gas tax for California. Energy Policy, 37 (12), 5173-5183.

Lin, C.-Y.C., and J.(J.) Zeng. (2013). The elasticity of demand for gasoline in China. Energy Policy, 59, 189-97.

Lin, C.-Y.C., and J.(J.) Zeng. (2014). The optimal gasoline tax for China. Theoretical Economics Letters, 4 (4), 270-278.

Liu, Q., and C.-Y.C. Lin Lawell. (2020). The effects of public transportation and the built environment on the number of civilian vehicles in China. Working paper, Cornell University.

Lyon, T.P., Y. Lu, X. Shi, and Q. Yin. (2013). How do investors respond to green company awards in China? Ecological Economics, 94, 1-8.

Manski, C.F. (1995). Identification Problems in the Social Sciences. Cambridge, MA: Harvard University Press.

McFadden, D. (1973). Conditional logit analysis of qualitative choice behavior. In P. Zarembka (Ed.), Frontiers in Econometrics. New York: Academic Press.

McFadden, D. (1974). The measurement of urban travel demand. Journal of Public Economics, 3 (4), 303-328.

Lyon, T.P., M. Michelin, A. Jongejan, and T. Leahy. (2012). Is "smart charging" policy for electric vehicles worthwhile? Energy Policy, 41, 259-268.

Miravete, E.J., M.J. Moral, and J. Thurk. (2018). Fuel taxation, emissions policy, and competitive advantage in the diffusion of European diesel automobiles. RAND Journal of Economics, 49 (3), 504-540.

Moon, H.R., M. Shum, and M. Weidner. (2018). Estimation of random coefficients logit demand models with interactive fixed effects. Journal of Econometrics, 206 (2), 613-644.

Muehlegger, E., and D.S. Rapson. (2019). Subsidizing mass adoption of electric vehicles: Quasi-experimental evidence from California. Working paper, University of California at Davis.

Nienhueser, I.A., and Y. Qiu. (2016). Economic and environmental impacts of providing renewable energy for electric vehicle charging - A choice experiment study. Applied Energy, 180, 256-268.

Pathak, P., and P. Shi. (2017). How well do structural demand models work?: Counterfactual predictions in school choice. NBER Working Paper No. 24017.

Petrin, A. (2002). Quantifying the benefits of new products: The case of the minivan. Journal of Political Economy, 110 (4), 705-729.

Qian, J. (2018). Evaluating the electric vehicle subsidy program in China. Working paper, Cornell University.

Reynaert, M., and F. Verboven. (2014). Improving the performance of random coefficients demand models: The role of optimal instruments. Journal of Econometrics, 179 (1), 83-98.

Sallee, J.M. (2011). The surprising incidence of tax credits for the Toyota Prius. American Economic Journal: Economic Policy, 3, 189-219.

Sallee, J.M., and J. Slemrod. (2012). Car notches: Strategic automaker responses to fuel economy policy. Journal of Public Economics, 96, 981-999.

Sallee, J.M., S.E. West, and W. Fan (2016). Do consumers recognize the value of fuel economy: Evidence from used car prices and gasoline price fluctuations. Journal of Public Economics, 135, 61-73.

Sears, L., C.-Y.C. Lin Lawell, and M.T. Walter. (2020). Groundwater under open access: A structural model of the dynamic common pool extraction game. Working paper, Cornell University.

Shao, J., H. Yang, and A. Zhang. (2019). Adoption of electric vehicles: Manufacturers' incentive and government policy. Journal of Transport Economics and Policy, 53 (2), 175-198.

Sheldon, T.L., and J.R. DeShazo. (2017). How does the presence of HOV lanes affect plug-in electric vehicle adoption in California?: A generalized propensity score approach. Journal of Environmental Economics and Management, 85, 146-170.

Sheldon, T.L., J.R. DeShazo, and R.T. Carson. (2017). Electric and plug-in hybrid vehicle demand: lessons for an emerging market. Economic Inquiry, 55 (2), 695-713.

Siebert, R.B. (2017). A structural model on the impact of prediscovery licensing and research joint ventures on innovation and product market efficiency. International Journal of Industrial Organization, 54, 89-124.

Sun, Q., F. Wu, S. Li, and R. Grewaj. (forthcoming). Consumer boycotts, country of origin, and product competition. Management Science.

Train, K.E., and C. Winston. (2007). Vehicle choice behavior and the declining market share of U.S. automakers. International Economic Review, 48 (4), 1469-1496.

Tse, A. and J. Wu. (2018). Why 'Made in China 2025' triggered the wrath of President Trump. South China Morning Post, 11 September 2018. URL: https://multimedia.scmp.com/news/china/article/made-in-China-2025/index.html

Ullman, D.F. (2016). A difficult road ahead: Fleet fuel economy, footprint-based CAFE compliance, and manufacturer incentives. Energy Economics, 57, 94-105.

Wang, Y., J. Teter, and D. Sperling. (2011). China's soaring vehicle population: Even greater than forecasted? Energy Policy, 39, 3296-3306.

Woo, C.K., I. Horowitz, S. Luk, and A. Lai. (2008). Willingness to pay and nuanced cultural cues: evidence from Hong Kong's license-plate auction market. Journal of Economic Psychology, 29, 35-53.

Wu, F., Q. Sun, R. Grewal, and S. Li. (2019). Brand name types and consumer demand: Evidence from China's automobile market. Journal of Marketing Research, 56 (1), 158-175.

Xiao, J., and H. Ju. (2014). Market equilibrium and the environmental effects of tax adjustments in China's automobile industry. Review of Economics and Statistics, 96 (2), 306-317.

Xiao, J., X. Zhou, and W.-M. Hu. (2017). Welfare analysis of the vehicle quota system in China. International Economic Review, 58 (2), 617-650.

Yang, J., A.A. Liu, P. Qin, and J. Linn. (2020). The effect of vehicle ownership restrictions on travel behavior: Evidence from the Beijing license plate lottery. Journal of Environmental Economics and Management, 99, 102269.

Zhou, Y., and S. Li. (2018). Technology adoption and critical mass: The case of U.S electric vehicle market. Journal of Industrial Economics, 66 (2), 423-480.

Table 1. 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 2. Own-price and cross-price elasticities

Vehicle Model	Own-Price Elasticity	Cross-Price Elasticity with respect to the price of Buick E-assist 2.4L hybrid
Focus 1.8L	-52.666	0.000
C-Quatre 1.6L	-50.341	0.000
Eado 1.6L	-38.229	0.000
Gran Lavida 1.6L	-75.436	0.000
Jetta 1.6L	-40.909	0.000
Buick Excellegt 1.5L	-46.862	0.000
Bora 1.6L	-52.098	0.000
Langdong 1.6L	-66.084	0.000
Verna 1.4L	-39.212	0.000
Cruz 1.6L	-63.260	0.000
Corolla Ex 1.6L	-44.728	0.000
Corolla	-58.988	0.000
Octavia 1.6L	-60.071	0.000
Lotus L5	-54.566	0.000
H6 1.5T	-52.277	0.000
Honda CR-V 2.4L	-118.980	0.000
Tiguan 1.8T	-99.631	0.000
ix35 2.0L	-81.194	0.000
Touran 1.4T	-72.159	0.000
Succe1.5L	-30.919	0.000

Note: Own-price and cross-price elasticities are calculated using parameter estimates from Specification (1) of Chen and Lin Lawell (2021b).

Table 3. Counterfactual new alternative vehicle simulations

	Difference from status quo base case in:				
	Alternative vehicle market share	Consumer surplus (1000 Yuan)	Average private firm profit (billion Yuan)	Average state-owned firm utility (billion Yuan)	Utility of firm producing the new car (billion Yuan)
New car is like the "Buick E-assist 2.4L hybrid" except:					
fuel efficiency is 25% more fuel efficient	0.000094	155.10	10.26***	6.58	23.75
length is 25% longer	0.000079	58.20	17.85***	11.05	25.52
weight is 25% heavier	0.000082	110.60	23.36***	10.97	30.42
weight is 25% lighter	0.000051	225.50	7.21**	8.32	29.22
one more seat	0.000141	136.20	19.66***	13.80	35.73
horsepower is 25% higher	0.000012	33.50	-1.00	1.36	7.29***
horsepower is 25% lower	0.000165	129.1	22.16***	11.50	29.46
firm does not have an international joint venture	0.000116	211.70	15.41***	10.85	34.87
produced by a private firm that has an international joint venture	-0.000037	132.10	-26.08	-0.17	11.58
produced by a private firm without an international joint venture	0.000117	292.80	-11.47	7.67	30.20

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