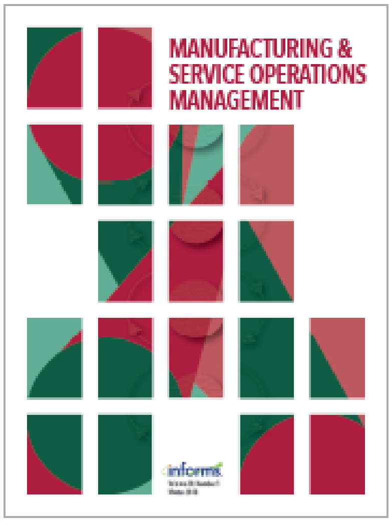

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The Car Sharing Economy: Interaction of Business Model Choice and Product Line Design

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Abstract. Several auto manufacturers have recently introduced car sharing programs. Although the structure of most programs is the same, there is no clear dominant strategy for the type of vehicles that should be provided through car sharing. In this paper, we consider an original equipment manufacturer (OEM) that contemplates car sharing and designs its product line by accounting for the trade-off between driving performance and fuel efficiency under CAFE standards. Customers have different valuations of driving performance and decide whether to buy, join car sharing or rely on their outside options. We find that the OEM increases the fuel efficiency of the vehicles it provides through car sharing. This higher efficiency enables the OEM to charge a higher selling price to the higher end of the market, thus increasing its profit. This is especially beneficial to higher-end OEMs that face greater cannibalization and can explain why Daimler and BMW have been particularly active in introducing car sharing. Offering car sharing is not always environmentally beneficial. Even when it is, we find that doing so may reduce the OEM's Corporate Average Fuel Economy (CAFE) level. In such cases, incentive multipliers should be granted for each shared car. Finally, if anticipating aggressive CAFE standards, OEMs may introduce car sharing to better absorb the increase in the production cost.

Supplemental Material: The online appendix is available at https://doi.org/10.1287/msom.2016.0605.

Keywords: car sharing • sustainable business models • CAFE standards • fuel efficiency • product line

1. Introduction

In recent years, car sharing has been increasingly seen as a viable alternative to car ownership. Under a typical car sharing model, after paying a yearly fee, customers become members of the car sharing program and obtain access to a fleet of vehicles that they can use in increments as short as one hour. Members are charged based on the duration of the time they remove a vehicle from the service pool; gas, maintenance, and insurance are included in the hourly price. In this manner, car sharing transforms the fixed costs associated with vehicle ownership (e.g., purchase cost, depreciation, insurance) to a variable cost that depends on vehicle use. According to Shaheen and Cohen (2015) the number of car sharing members in the United States has increased from 52 thousand in 2004 to 1.28 million in 2015. Navigant Research (2013) estimates that by 2020 the global car sharing market will be worth \$6.2 billion in revenues.

Although in a car sharing program customers buy the use, rather than the ownership a vehicle, several original equipment manufacturers (OEMs) have recently begun introducing car sharing schemes. Daimler and BMW have been particularly active in including car sharing in their business models. Daimler was the first OEM to introduce a car sharing program in 2010, in the city of Austin, Texas. Since then, it has expanded in several cities across the United States and Europe (Car2Go 2016) and has become the largest car sharing provider in the world counting more than 1 million members (PRNewswire 2014).[1] BMW operates a similar scheme in Seattle, Washington, and Portland, Oregon (ReachNow 2016) and several European locations. In Germany, BMW is the largest car sharing provider with almost 500 thousandmembers (Statista 2016). In addition to Daimler and BMW, Peugeot, Volkswagen, and Ford operate car sharing programs in several European cities (Mu 2016, Quicar 2016, Ford 2015). Only recently, GM created its own car sharing program (Maven 2016) in Ann Arbor, Michigan, and has quickly expanded in several U.S. locations now serving over 5 thousand members (Etherington 2016). Such moves are indicative of a broader transformation that OEMs are undergoing to become mobility companies (Nusca 2015, Hall-Geisler 2016).

Another interesting aspect of the OEMs' recent involvement in the car sharing business is the choice of vehicle models they provide in their car sharing programs. Daimler only offers its highest efficiency Smart Fortwo model. BMW offers a wider range of models: the electric BMW i3, the fuel-efficient MINI Cooper hatchbacks, and the BMW 328xi. This range of vehicles is concentrated on the higher end of BMW's efficiency portfolio. Similarly, GM's choice of vehicle models include the electric Volt and the fuel-efficient Chevrolet Cruze and Spark. These practices suggest that car sharing draws on a narrower set of models than are available for sale, and raises the question of what type of vehicles OEMs should provide in a car sharing program.

From a technology-based point of view, when determining their product line, OEMs try to balance the trade-off between driving performance and fuel efficiency. Besides the obvious cost implications this may entail, high-end OEMs may be more reluctant to drastically improve fuel efficiency due to fears of sacrificing driving performance such as acceleration or horsepower. Car sharing offers advantages that may make it more attractive for these OEMs to produce higher efficiency vehicles. First, under car sharing, the providing firm is typically responsible for the operating cost of the vehicle, which is lower for higher-efficiency vehicles. Second, due to the pooling effect of car sharing, OEMs can realize savings in the total production cost, allowing them to produce more efficient vehicles. Third, the implications of the efficiency versus performance trade-off may be less pronounced as an OEM could achieve better price discrimination by selling high-performing vehicles to the customers who value driving performance more and offering car sharing to the customers who value fuel efficiency more.

From a market-based point of view, the decision on the type of vehicle and business model to provide depends on management of the well known trade-off between market expansion and cannibalization. On the one hand, providing car sharing services may cannibalize the demand from customers who would otherwise purchase vehicles and, therefore, may decrease the manufacturers' profitability. On the other hand, car sharing can benefit the OEMs by potentially expanding the customer base to segments that previously did not own a car. For instance, a car sharing scheme may appear attractive to commuters who normally use alternative transportation modes such as public transportation. Even in the absence of such a market expansion effect, OEMs may benefit from a decrease in their total production cost through a pooling effect as, under car sharing, the same vehicle can be used by many customers at different periods of time, resulting in a lower production volume.

The interaction between the choice of business model and the product line design can be particularly important to OEMs because of the evolving environmental regulations around emission standards. Specifically, automotive industry OEMs are required to comply with the Corporate Average Fuel Economy (CAFE) standards set by the U.S. Department of Transportation (USDOT). Although this regulation has been in effect since 1975, the standards are scheduled to increase rapidly over the next few years with the target for 2025 set at 54.5[2] miles per gallon (USDOT 2012). Surveying the average fleet efficiency of different OEMs reveals that BMW and Daimler, along with other high-end OEMs such as Jaguar and Volvo, have been among the least fuel-efficient manufacturers (see summary prepared by the NHTSA 2014). Interestingly, Daimler and BMW have also been among the first manufacturers to actively engage in the car sharing business.

The objective of the CAFE regulation is to incentivize OEMs to improve the fuel efficiency of their vehicles. However, the scope of this regulation does not capture whether providing car sharing increases or decreases the environmental impact of OEMs. On the positive side, the U.S. Environmental Protection Agency (EPA) has categorized car sharing as a top-10, high-potential "green" business model (U.S. EPA 2009). The main argument in support of the green benefits of car sharing is that it allows customers to satisfy their mobility needs without owning a vehicle. Along these lines, Navigant Research (2013) estimates that each shared car takes approximately 5 to 11 vehicles off the road. Shaheen and Cohen (2015) estimate this number to be 9 to 13 vehicles. On the negative side, however, by reaching out to customers who previously did not own a vehicle and enabling them to start using one, car sharing can increase the overall environmental impact of transportation.

In this paper, we consider an OEM that contemplates introducing car sharing to complement its traditional sales business model. We focus on customers whose driving needs do not force them to rule out car sharing as a viable transportation option (e.g., we do not consider customers with long daily commutes to and from work). The market comprises customers who differ with respect to how much they value vehicle driving performance (e.g., acceleration/horsepower). In addition to deciding whether to change its business model by including car sharing, the OEM designs its product line by determining the driving performance of the vehicles targeted at these segments via selling or car sharing. It is well known that driving performance comes at the expense of fuel efficiency (Wong 2001, Knittel 2009, Berry 2010, National Research Council 2015). Accounting for this trade-off[3] is very important because it affects the OEM's ability to comply with the CAFE standards, which are scheduled to steeply increase in the near future. To capture the cost benefits of offering car sharing, we use a closed queueing network approximation, which operationalizes the pooling effect of car sharing while maintaining analytical tractability. To our knowledge this is the first paper to account for the OEM's business model choice and product line design in the presence of environmental regulation. Our analysis generates new and interesting insights not identified by previous research.

We find that providing car sharing may allow an OEM to increase its per-unit profit from selling cars. This is driven by the interaction between the OEM's business model and product line decisions. Specifically, we find that the OEM should choose different efficiencies for the vehicles it sells versus the vehicles it dedicates to car sharing. The fuel efficiency of the vehicles sold to the higher end of the market is not affected by the OEM's decision to introduce car sharing. The lower end of the market values efficiency more than the higher end, which emphasizes driving performance instead. For this reason, and given the cost benefits of pooling, the OEM improves, at the expense of the driving performance, the efficiency of the shared vehicles. In other words, it provides vehicles of higher fuel efficiency to the lower end of the market when offering car sharing than when selling. By doing so, it also weakens the potential cannibalization as car sharing becomes less attractive to the higher end of the market. This allows the OEM to set a higher selling price for the vehicles targeted at this segment.

With respect to environmental regulation, our findings suggest that OEMs offering car sharing should be granted incentive multipliers so that each shared car they provide counts as more than one vehicle in the compliance calculation. Otherwise, introducing car sharing may result in a lower CAFE level. The reason is that, although the pooling effect of car sharing enables the OEM to produce vehicles of higher efficiency, it also decreases the number of (the more efficient) vehicles required to meet customers' needs, lowering the average fleet efficiency. This may dissuade OEMs from introducing car sharing even for cases where, in the absence of stringent CAFE standards, car sharing is economically and environmentally beneficial. This finding has clear policy implications as it points to the need for aligning existing environmental regulation with emerging business models. When the CAFE standards are binding, we find that more aggressive standards increase the appeal of car sharing to OEMs. The reason is that car sharing mitigates the total cost of producing vehicles with higher efficiency.

Finally, we find that "high-end" OEMs benefit more from introducing car sharing than "low-end" OEMs. This is because when only selling vehicles, these OEMs serve only a part (the higher end) of the market as they face greater potential cannibalization. Car sharing allows them to serve additional customers without cannibalizing existing sales. This finding may help explain why Daimler and BMW have been particularly active in the car sharing business.

2. Literature Review

Car sharing programs fall under a new class of business models, often referred to as *servicizing* business models (Rothenberg 2007), in which the use, rather than ownership, of the products governs the relationship between manufacturers and customers. Such business models have attracted research interest in a variety contexts. For instance, Corbett and DeCroix (2001) and Corbett et al. (2005) analyze the shared-saving contracts implemented for chemical management services; Toffel (2008) discusses the agency problems that arise in servicizing business models; Kim et al. (2007) and Guajardo et al. (2012) study the implications of performance-based contracting on supply chain relationships and product reliability, respectively; and Chan et al. (2014) investigate how the pricing structure (pay-per-use versus fixed-fee) of different maintenance service offerings for medical devices affect service performance. In this stream of research our paper is closer to Agrawal and Bellos (2016), who analyze the effect of the structural characteristics of servicizing business models on overall environmental performance. However, they do not consider a product line and they do not analyze the effect of environmental regulation on the OEM's strategy. Both elements are particularly relevant in the automotive industry, where all OEMs (i) offer a line of products and (ii) are subject to the CAFE regulation. By examining these issues, we provide insights not identified in previous research. For instance, we find that although including car sharing may lower the OEM's environmental impact, it may also lower the average fleet efficiency which, in the presence of regulation, may disincentivize OEMs from offering car sharing. Overall, we contribute to the growing stream of research that rigorously evaluates innovative business models (Girotra and Netessine 2013) by assessing their environmental and economic performance.

With respect to business models pertinent to the automotive industry, a number of studies (Lifset and Lindhqvist 1999, Fishbein et al. 2000, Agrawal et al. 2012) have assessed the "green" potential of leasing as a business practice. The main question of these studies is whether the manufacturers can and will efficiently remarket the used products and extend their effective life. Car sharing differs from leasing in three important aspects that have not been previously studied. First, the customer's payment is directly linked to vehicle use. Second, the vehicle production volume may be smaller due to pooling effects. Third, the car sharing provider is responsible for the vehicle operating cost.

Closer to our transportation context, Lim et al. (2015) investigate how customer characteristics such as range and resale anxiety affect the adoption of electric vehicles and, as an extension, the OEM's profitability and consumer surplus. Avci et al. (2015) study the adoption of electric vehicles offered under different operational structures (i.e., with or without battery-switching stations) and the environmental implications resulting from such adoption. Although these papers share conceptual similarities, their scope is different: Our focus is product–market business models, whereas their focus is post-sales operating models to service purchased products (i.e., battery charging for electric vehicles). Furthermore, we capture the interplay between conventional sales and car sharing business models offered by the same OEM, while these papers focus on a third-party service provider who provides battery switching services. Avci et al. (2015) examine the effect of counter-risk pooling, which implies that the provider needs to maintain more batteries than the actual number of customers. In our setting, customers' mobility needs can be satisfied through a smaller pool of vehicles than the number of members in the car sharing scheme. We analyze this pooling effect through a queuing approximation that maintains analytical tractability. With respect to research on the car sharing model, He et al. (2017) determine the service region design along with the optimal fleet size of one-way car sharing providers, but no product design decisions are considered.

While the effect of customer heterogeneity on product line decisions has been previously studied in the literature from economic (Moorthy 1988, Moorthy and Png 1992, Netessine and Taylor 2007) and environmental (Chen 2001, Biller and Swann 2006) points of view, guidelines for the OEM's strategy cannot be directly inferred from this work. The reason is that the previous research has allowed for different product qualities but has assumed the same (sales) business model. In our context, the customer's decision between buying a vehicle and joining a car sharing program does not entail only the comparison of two vertically differentiated (i.e., different quality) products. It also entails the comparison of two different pricing schemes corresponding to the two business models.

By accounting for the product design and the business model choice, we generate new insights about the appeal of car sharing to OEMs. For instance, we find that the pooling effect of car sharing enables the OEM to choose vehicles of higher efficiency. This allows the OEM to exercise better price discrimination and increase its profit from selling vehicles. Previous research suggests that in markets with heterogeneous product valuations (e.g., in markets that can be described by high and low segments) OEMs face greater potential cannibalization for larger valuations of the high segment. In this case, OEMs implement an exclusion policy (Netessine and Taylor 2007) by serving only the high-valuation customers (Moorthy and Png 1992). By contrast, we find that the larger valuations of the high segment increase the OEMs' benefit more from serving both segments and, more specifically, from selling vehicles to the customers that value driving performance more and providing car sharing to the customers that value fuel efficiency more. This finding may help explain why higher-end OEMs such as BMW and Daimler have been particularly active in introducing car sharing programs.

Finally, we contribute to the emerging stream of research that studies the effect of environmental regulation on the firm's decisions. Previous research has focused on decisions such as technology choice (Drake 2016), product introduction (Plambeck and Wang 2009), product design (Chen 2001, Subramanian et al. 2009, Kraft et al. 2013, Esenduran and Kemahlıoğlu-Ziya 2015, Huang et al. 2015), and operating strategy (Ata et al. 2012). We add to this literature by considering the choice of a business model. We explicitly include the model of car sharing and find that environmental regulations mandating average-based efficiency standards may underestimate the environmental performance of a business model, therefore disincentivizing OEMs from offering it. Although the pooling effect of car sharing enables the OEM to produce vehicles of higher fuel efficiency, it also reduces the number of such vehicles produced, resulting in lower CAFE levels. This issue has not been identified in previous research on CAFE regulation (Chen 2001, Jacobsen and van Benthem 2015), which has focused primarily on conventional sales models.

3. The Model

We develop a model where a monopolist OEM sells cars, which is our benchmark *Ownership* mobility option, and may also introduce a car sharing program in the same market, which is our *Membership* mobility option. The OEM is subject to an average fleet fuel efficiency standard such as the CAFE standard (NHTSA 2016) whereby the USDOT holds automotive OEMs accountable for meeting increasingly aggressive standards (Spector and Rogers 2015). In addition to deciding whether to offer *Membership*, the OEM determines its product line. In particular, the OEM determines the specifications, such as driving performance and fuel efficiency, of the different vehicles it produces.

For simplicity, our modeling of product line design is based on a single vehicle style (e.g., mid-size sedan; see Michalek et al. 2004). This is a meaningful unit of analysis as there can be substantive differences within the same vehicle style, and even within the same car model. For example, Chevrolet's 2015 Impala and SS are categorized as large cars. The driving performance of the Impala is rated at 8.6/10 with 22–31 mpg, and the driving performance of the SS is rated at 9.5/10 with 14–21 mpg (*U.S. News* 2015). *Consumer Reports* (2015) rates the driving performance and fuel efficiency of the Chevrolet Equinox V6 AWD as very good and poor, respectively, whereas it rates both as fair for the Chevrolet Equinox 2.4L AWD.

We assume that customers are heterogeneous in their preferences for vehicle attributes. Existing empirical research provides insight into the most significant dimensions in market heterogeneity. In particular, Boyd and Mellman (1980) find significant dispersion in the preferences for price, acceleration, and style (defined as the sum of exterior length and width, divided by exterior height). Berry et al. (1995) draw similar conclusions. More recently, Guajardo et al. (2016) identified price, length of warranty, product quality, and horsepower-to-weight as the main determinants of the demand for vehicles. Paralleling Boyd and Mellman (1980), their study indicated significant dispersion in customer preferences for horsepower-to-weight, a proxy for acceleration; see Berry et al. (1995). Given that in our model we focus on a single vehicle style and endogenize vehicle prices, and that vehicle quality or warranty do not usually vary for the same OEM, we focus on customer heterogeneity with respect to driving performance.

Specifically, we consider a market with two segments that differ with respect to how much they value driving performance. The OEM designs its product line by determining the driving performance of the vehicles targeted (through *Ownership* or *Membership*) at each segment. We use $w \in [0,1]$ to denote the vehicle driving performance and we explicitly account for the inherent trade-off between driving performance and fuel efficiency (Wong 2001, Knittel 2009, Berry 2010, National Research Council 2015). To do so in an analytically tractable manner we follow Chen (2001) and assume that $w = 1 - e$, where $e \in [0,1]$ is the fuel efficiency. Hence, by determining w the OEM indirectly determines e and vice-versa. To avoid repetition, in the rest of the paper we refer only to the choice of fuel efficiency as the OEM's main product design decision.

When selling, the OEM also determines the vehicle selling price F. When offering *Membership*, the OEM determines the use fee p per unit of time and the size S of the car sharing fleet that ensures an industry-determined level of availability $a \in (0,1)$, where a value of 1 corresponds to customers always finding a car available.

In principle, the availability level a may constitute another decision lever for the OEM. However, given that car sharing programs are marketed as a viable alternative to car ownership, for which the availability level is very high, the OEM has limited latitude in choosing a. Furthermore, evidence from practice suggests that car sharing providers always strive to ensure a high service level (Frei 2005, Brady 2013).[4] Thus, we make a exogenous in our model. Similarly, in addition to the use fee, some car sharing providers may charge members a fixed fee to join. For instance, Car2Go and ReachNow charge a one-time-only application fee of \$35. Such amounts are rather trivial compared with the fixed costs of car ownership. Thus, we assume that they do not influence the customers' choice between *Ownership* and *Membership* and normalize them to zero.

Introducing *Membership* in conjunction with *Ownership* may (i) expand the OEM's market and attract customers who would otherwise resort to alternative modes of transportation (e.g., public transportation) and/or (ii) cannibalize vehicle sales. Thus, the OEM sets the driving performance (equivalently, the fuel efficiency) of the vehicles, the prices F and p, and the fleet size S that balance the trade-off between market expansion and cannibalization.

Customers observe the OEM's decisions and cover their transportation needs by choosing a product design and mobility option $j \in \{O, M, \varnothing\}$, where O stands for *Ownership*, M for *Membership*, and $\varnothing$ for the *Outside Option* (e.g., public transportation). To determine its optimal strategy, the OEM factors in the customers' response. Therefore, we proceed by formulating a Stackelberg game in which the OEM moves first and then we analyze the customers' and the OEM's problems by applying backward induction. Hence, we begin with the customers' problem formulation.

3.1. The Customers' Utility Model

As discussed earlier, we focus on consumer heterogeneity with respect to preferences for driving performance (equivalently, fuel efficiency). While all customers prefer a higher driving performance to a lower performance, they differ in the strength of their valuation for performance. Specifically, we consider two customer segments H and L (high and low) of sizes n_H and n_L, where the valuation of segment H customers for driving performance is θ_H, and that of the segment L customers is θ_L, with $\theta_H > \theta_L > 0$.

In practice, different customers use vehicles for different purposes. It would be unrealistic to claim that car sharing can be a viable transportation alternative for all customers. For instance, a customer who has long daily commutes to work that includes significant idle time during working hours or a customer who mainly uses a car for time-sensitive professional activities such as delivery may not find car sharing attractive due to the higher overall cost and the lack of availability guarantee. Our model effectively focuses on that segment of the market whose driving needs do not force them to rule out *Membership* as an option. In many major cities with dense and centralized populations, such a subset can be of considerable size. For simplicity, we consider this smaller subset of the overall population to be homogeneous with respect to their vehicle use needs and their valuation of vehicle use. Cervero et al. (2007) provide evidence of such relative homogeneity as they find that most of the car sharing trips

Table 1. Notation, $i \in \{H, L\}$

Symbol	Definition
	Parameters
θ_i	Valuation of driving performance
$w = 1 - e$	Driving performance
$d \in (0, 1)$	Customers' vehicle use need
v	Valuation of vehicle usage
n_i	Size of customer segment i
$a \in (0, 1)$	Service level (vehicle availability) under *Membership*
$S(a)$	Number of vehicles that achieve an availability level a
g	Vehicle operating cost
c_w	Unit production cost of driving performance
c_e	Unit production cost of fuel efficiency
$r \in [0, 1]$	OEM's CAFE level
$R \in [0, 1]$	CAFE standard
	Decision variables
Pricing	
F	Selling price
p	Per-unit-of-time price
Product Design	
$e \in [0, 1]$	Vehicle fuel efficiency

serve similar (e.g., shopping and social/recreational) purposes.[5] In particular, we denote by d the customers' transportation needs as a fraction of the vehicle's useful life, which we normalize to one time period. The customers' per-unit-of-time valuation of using the vehicle to meet their driving needs is v and the per-unit-of-time operating cost (i.e., cost of gas and maintenance) is g. In Table 1, we summarize the notation used throughout the paper.

Note that our assumption of homogeneous driving needs does not imply that all markets are characterized by the same d and v. For example, college students are relatively homogeneous in their vehicle use needs and the valuation of these needs as they have similar work schedules and lifestyles. However, the needs and valuations of the college students of a rural campus may differ significantly from the needs and valuations of the college students of an urban campus (e.g., due to lack of a public transportation network). In practice, car sharing prices may vary across markets, and even across neighborhoods, reflecting local market characteristics. Although such market-by-market positioning of the *Membership* offering is beyond the scope of our paper, our model can be solved using the parameter values from any particular area.

We define the utility that the customers of segment $i \in \{H, L\}$ derive over the vehicle's useful life when their mobility needs are satisfied through *Ownership* with a vehicle of efficiency e at price F as $U_i^O(e, F) = d(v + \theta_i w - g(1 - e)) - F$. The base utility dv that customers derive from satisfying their mobility needs (e.g., from running errands) is augmented by $d\theta_i w$. That is, between two customers with the same valuation of performance θ_i, the customer who satisfies his needs through a vehicle with a higher driving performance derives a higher utility. The total operating cost is modeled as $dg(1 - e)$ to capture the fact that it decreases in the vehicle's fuel efficiency. Customers also incur the purchase cost F, which represents the price of the vehicle. Given that $w = 1 - e$, the utility can be rewritten as

$$U_i^O(e, F) = d(v + (\theta_i - g)(1 - e)) - F.$$

Clearly, improvements in fuel efficiency positively contribute to U_i^O only for those customers with $\theta_i < g$; i.e., those customers who value efficiency more than driving performance. For customers with $\theta_i > g$, any improvement in fuel efficiency decreases their total utility as it lowers the vehicle's driving performance. To represent a market with both types of customers, we focus on the cases with $\theta_H > g > \theta_L > 0$.

We define the utility that the customers of segment $i \in \{H, L\}$ derive when their mobility needs are satisfied through *Membership* with a vehicle of efficiency e at a per-unit-of-time price p as $U_i^M(e, p) = ad(v + \theta_i w - p)$. Similar to the *Ownership* case, the customers' utility depends on the extent of the vehicle use and driving performance. However, compared with the utility under *Ownership*, the utility under *Membership* presents two important differences. First, instead of a fixed fee F, customers pay a per-unit-of-time price p. For a given price p, and unlike in the case of *Ownership*, a vehicle of higher fuel efficiency does not decrease the total operating cost dp that customers incur. Second, the customers' requests will be satisfied only a fraction of time, a. For the times that customers cannot find a vehicle available, we assume that they resort to their *Outside Option* (e.g., public transportation), the utility of which we normalize to zero (i.e., $U_i^{\varnothing} = 0$). Given that $w = 1 - e$, the utility can be rewritten as

$$U_i^M(e, p) = ad(v + \theta_i(1 - e) - p).$$

In our utility model, we assume that any possible idle time is negligible compared with d. While this assumption is not appropriate for trip purposes such as commuting to work, as in these cases the vehicle remains idle for several hours during each round-trip, Millard-Ball et al. (2005) find that car sharing is rarely used for such purposes. Newer car sharing models such as Car2Go use a one-way model allowing the customer to drop the vehicle off in any location within a service region (He et al. 2017), in which case this assumption is even more applicable.

3.2. The OEM's Problem

We consider markets where the OEM is already present by selling to both customer segments (i.e., the OEM has induced the (O, O) equilibrium) or only to the high segment (i.e., the OEM has induced the $(O,\varnothing)$ equilibrium). To match closest to what is observed in practice, we exclude the extremely unlikely cases where an OEM would switch completely away from a selling strategy or only offer *Membership* to the high segment. Hence, in our model the OEM's business model choice pertains to whether it should induce the (O,M) equilibrium by providing car sharing to the low segment of the market. The robustness of our conclusions to this assumption is discussed after the proof of Corollary 1 in the online supplement. We continue by constructing the OEM's profit function.

Improvements in the vehicle's driving performance or fuel efficiency present more technical challenges at higher levels of w and e, respectively. For that reason, we assume that the unit production cost of a vehicle with w and e levels is given by $c_w w^2 + c_e e^2$, where $c_w, c_e > 0$ (for a similar cost structure, see Chen 2001). The profit that the OEM appropriates from selling to segment i vehicles of fuel efficiency e at a price F is

$$\Pi_i^O(F,e) = (F - c_w w^2 - c_e e^2)n_i = (F - c_w(1-e)^2 - c_e e^2)n_i,$$

where n_i is the size of segment i.

The profit that the OEM realizes from covering the mobility needs of segment i through *Membership* at a reservation rate p, using vehicles of fuel efficiency e, is $\Pi_i^M(p,e) = a(p - g(1-e))n_i d - (c_w w^2 + c_e e^2)S(a)$. Here $S(a)$ is the number of shared vehicles through which the OEM meets a service level a. We elaborate on the relationship between S and a in Section 4. For the fraction of time a that customers find a vehicle available, the OEM gains a revenue $pn_i d$, where $n_i d$ is the aggregate vehicle use of segment i. However, for the same fraction of time, the OEM incurs a total operating cost of $g(1-e)n_i d$, which decreases in the vehicle's fuel efficiency. Similar to the case of *Ownership*, the total production cost depends on the marginal costs c_w and c_e as well as the driving performance $w = 1-e$ and fuel efficiency e except that now the total number of vehicles is $S(a)(\le n_i)$. Therefore, the OEM's profit under car sharing is

$$\Pi_i^M(p,e) = a(p - g(1-e))n_i d - (c_w(1-e)^2 + c_e e^2)S(a).$$

Having introduced Π_i^O and Π_i^M, we next formulate the OEM's problem of maximizing the total profit from each of the $(O,\varnothing)$, (O,O), and (O,M) equilibria. The OEM cannot directly observe the valuations of each customer. Because of this information asymmetry the OEM maximizes its profit subject to the individual rationality and incentive compatibility constraints relevant to each equilibrium. The OEM's optimization problem associated with each equilibrium entails the calculation of the fuel efficiencies and prices that will induce customers to (most profitably for the OEM) self-select into that market equilibrium.

Under (O,M), the OEM sells one of its products and markets the other through car sharing. The *Ownership* option is targeted at the high segment and the *Membership* option is targeted at the low segment. In particular, the OEM calculates the profit maximizing efficiencies $e_H^*, e_L{}^*$ and the prices F^*, p^* that, in equilibrium, induce the high segment to choose *Ownership* and the low segment to choose *Membership*:

$$\Pi^*_{(O,M)} = \max_{e_H, e_L, F, p} \Pi_{(O,M)}(e_H, e_L, F, p) \quad \text{where}$$
$$\Pi_{(O,M)}(e_H, e_L, F, p) = \Pi_H^O(F, e_H) + \Pi_L^M(p, e_L)$$

s.t.

$$d(\nu + (\theta_H - g)(1-e_H)) - F \ge 0, \qquad (IR_O^H)$$
$$ad(\nu + \theta_L(1-e_L) - p) \ge 0, \qquad (IR_M^L)$$
$$d(\nu + (\theta_H - g)(1-e_H)) - F \ge ad(\nu + \theta_H(1-e_L) - p), \qquad (IC_O^H)$$
$$ad(\nu + \theta_L(1-e_L) - p) \ge d(\nu + (\theta_L - g)(1-e_H)) - F. \qquad (IC_M^L)$$

The individual rationality constraints IR_O^H and IR_M^L ensure that the customers of the high and low segments benefit from meeting their transportation needs through *Ownership* and *Membership*, respectively. The incentive compatibility constraints IC_O^H and IC_M^L ensure that the high segment prefers *Ownership* over *Membership* and the low segment prefers *Membership* over *Ownership*, respectively.

Under $(O,\varnothing)$ the OEM only sells vehicles and determines the efficiency e_H^* and price F^* that induce (i) the high segment to choose *Ownership* over the *Outside Option* and (ii) the low segment to choose the *Outside Option* over *Ownership*:

$$\Pi^*_{(O,\varnothing)} = \max_{e_H, F} \Pi_{(O,\varnothing)}(e_H, F) \quad \text{where}$$
$$\Pi_{(O,\varnothing)}(e_H, F) = \Pi_H^O(F, e_H)$$

s.t.

$$d(\nu + (1-e_H)(\theta_H - g)) - F \ge 0, \qquad (IR_O^H)$$
$$d(\nu + (1-e_H)(\theta_L - g)) - F < 0. \qquad (IR_O^L)$$

Under (O,O), the OEM only sells its products and determines the efficiencies $e_H^*, e_L{}^*$ along with the prices F_H^*, F_L^* (we use the subscript $i = H$ and $i = L$ to indicate the selling price charged to the high and low segment, respectively) that induce (i) both segments to choose *Ownership* over the *Outside Option* and (ii) the two segments to prefer the vehicle targeted at them:

$$\Pi^*_{(O,O)} = \max_{e_H, e_L, F_H, F_L} \Pi_{(O,O)}(e_H, e_L, F_H, F_L) \quad \text{where}$$
$$\Pi_{(O,O)}(e_H, e_L, F_H, F_L) = \Pi_H^O(F_H, e_H) + \Pi_L^O(F_L, e_L)$$

s.t.

$$d(v+(1-e_H)(\theta_H-g))-F_H \geq 0, \qquad (IR_O^H)$$
$$d(v+(1-e_L)(\theta_L-g))-F_L \geq 0, \qquad (IR_O^L)$$
$$d(v+(1-e_H)(\theta_H-g))-F_H \geq d(v+(1-e_L)(\theta_H-g))-F_L, \qquad (IC_O^H)$$
$$d(v+(1-e_L)(\theta_L-g))-F_L \geq d(v+(1-e_H)(\theta_L-g))-F_H. \qquad (IC_O^L)$$

Similar to Chen (2001) and without loss of generality, in the rest of the analysis we assume values of c_w and c_e such that the optimal fuel efficiency levels lie in the interior $(0,1)$ under all equilibria (e.g., we do not consider $c_w=0$ or $c_e=0$ as they result in $e_H^*=0$ and $e_L^*=1$, respectively). The OEM calculates the optima of the maximization problems and chooses the one that results in the most profitable market equilibrium. That is, $\{h^*,l^*\}=\arg\max\{\Pi^*_{(h,l)}\colon \Pi^*_{(O,M)}, \Pi^*_{(O,O)}, \Pi^*_{(O,\varnothing)}, \Pi^*_{(\varnothing,\varnothing)}=0\}$.

3.3. Modeling CAFE Standards

The maximization problems formulated above do not account for the fact that the OEM's CAFE level must satisfy existing CAFE standards, which we denote by $R\in[0,1]$. Currently in practice, the CAFE level for each OEM is calculated through the use of a harmonic mean. For instance, if an OEM produces two different types of vehicles (e.g., A and B) with fuel efficiencies e_A and e_B and at quantities n_A and n_B, then its CAFE level is given by the harmonic mean $r=(n_A+n_B)/(n_A/e_A+n_B/e_B)$. To keep the comparison of the CAFE levels across different equilibria analytically tractable, we base our calculations on a weighted average. For instance, using the same example we calculate the OEM's CAFE level as $r=(n_A/(n_A+n_B))e_A+(n_B/(n_A+n_B))e_B$.[6] Following previous literature (Biller and Swann 2006, Jacobsen and van Benthem 2015), we account for the effect of regulation by introducing the constraint $r\geq R$ in the OEM's maximization problem. Specifically, in our model the OEM determines the optimal efficiencies and prices which, in addition to the individual rationality and incentive compatibility constraints, also satisfy the following: (i) $(n_H/(n_H+S(a)))e_H+(S(a)/(n_H+S(a)))e_L\geq R$ under the (O,M) equilibrium; (ii) $(n_H/(n_H+n_L))e_H+(n_L/(n_H+n_L))e_L\geq R$ under the (O,O) equilibrium; and (iii) $e_H\geq R$ under the $(O,\varnothing)$ equilibrium.

Currently, OEMs that do not meet the standard R have the option of paying a civil penalty of $55 per mpg under R per vehicle produced. Given the highly positive public perception of the CAFE standards (see Program on International Policy Attitudes 2006, Greene 2010, National Research Council 2015) and the heightened attention to the matter due to recent emissions scandals (Tabuchi and Ewing 2016, Riley 2016), it is reasonable to expect that OEMs will refrain from making extensive use of this mechanism. Thus, treating R as a constraint can capture the essence and the main effect of regulation on the OEM's decisions.

4. Analysis and Results

Below we analyze the OEM's optimal business model and product line design strategy. For the model of car sharing we also characterize the OEM's optimal capacity decision. Furthermore, we determine the related economic and environmental implications, and we examine how such implications depend on the characteristics of the market served by the OEM as well as enactment of environmental regulation. When comparing across different equilibria we use the notation (h,l) with $h\in\{O\}$ and $l\in\{O,M,\varnothing\}$. For instance, $e_H^*(O,M)$ denotes the optimal fuel efficiency of the vehicles sold to the high segment under the (O,M) equilibrium. All technical proofs and analytical expressions are provided in the online supplement.

4.1. Capacity Decisions: The Pooling Effect

Under *Membership*, if the size of the fleet is S, then at any instance of time the total number of vehicles in circulation (i.e., vehicles that are idle or being used by the customers) is also S. This setting resembles the operation of a closed queueing network with a total of S jobs. For that reason, we model a network that comprises a single-server $\bullet/M/1$ node and an infinite-capacity $\bullet/G/\infty$ node (Figure 1(a)).

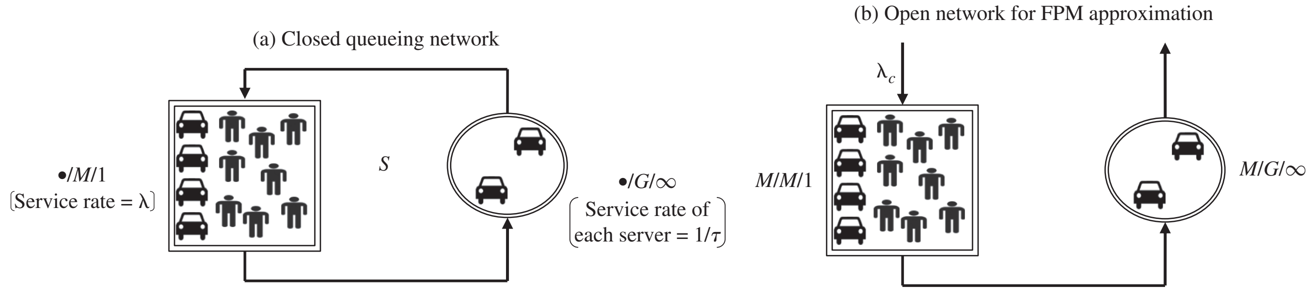
When a car is queued at the $\bullet/M/1$ node, it is waiting for the next customer request. Therefore, the service time at the $\bullet/M/1$ node represents the time between two consecutive customer requests. The idle time of the node represents the time when customer requests cannot be satisfied because no cars are available (see also Toktay et al. 2000). When a car leaves the $\bullet/M/1$ node, it serves a customer for the needed use duration and then returns to the $\bullet/M/1$ node. We assume that customer use times are independent and identically distributed and we capture the service process through the infinite capacity $\bullet/G/\infty$ node.

To calculate S, we use the fixed population mean ((FPM); see the online supplement for technical details) approximation developed by Whitt (1984) based on which we construct the open counterpart (see Figure 1(b)) of the closed queueing network and equate the expected equilibrium population of the open network to S. By doing so we obtain Remark 1.

Remark 1. The OEM's fleet size that achieves an availability level a when serving segment i through car sharing is given by $S(a)\approx a/(1-a)+an_id$.

In the online supplement, we provide the technical details about development of the approximation. The second term an_id in $S(a)$ represents the number

Figure 1. *Membership* as a Queuing Network



Notes. We view the car sharing system from a vehicle's perspective. The total number of vehicles circulating in the system is S. Vehicles are requested by customers with a rate λ and the average duration of each vehicle use is τ. For details see the online supplement.

of vehicles required to meet a service level a when customers' requests do not overlap. Specifically, $n_i d$ is the aggregate vehicle use generated by n_i customers during the useful life of a vehicle, which also represents the total service load that each vehicle can accommodate. We normalize the useful life of a vehicle to one. Under "perfect" pooling (i.e., no overlapping customer requests) the OEM can guarantee a service level a by providing as few as $an_i d$ vehicles. The first term $a/(1-a)$ in $S(a)$ is a correction term that adjusts this quantity to account for the fact that, in practice, customer requests may overlap.

Our formulation is based on the aggregate level of a single market (i.e., single geographic location), and does not account for capacity allocation issues (e.g., fleet rebalancing) across different locations in the same market. Such issues are outside the scope of this paper. For an excellent treatment of such operational considerations, see He et al. (2017). In what follows we characterize the OEM's pricing and product design strategy.

4.2. Product Line Decisions: Optimal Pricing and Fuel Efficiency

Because the OEM cannot observe the preferences θ_H and θ_L of individual customers, it chooses the prices and the fuel efficiencies of the vehicles such that customers self-select to a mobility/product design offering. We continue by characterizing the OEM's optimal product design (fuel efficiency) choice under each possible market equilibrium. In the remainder of the paper we assume that $n_L > 1/((1-d)(1-a))$; unless this condition holds, the (O, M) equilibrium is always dominated (see the online supplement).

Proposition 1. *The OEM chooses* $e_H^*(O,\varnothing) = e_H^*(O,O) = e_H^*(O,M) \doteq e_H^*$ *and* $e_L^*(O,M) > e_L^*(O,O) > e_H^*$. *Additionally,* $\partial e_H^*/\partial\theta_H < 0$, $\partial e_H^*/\partial d < 0$, *whereas* $\partial e_L^*(O,O)/\partial\theta_H > 0$, $\partial e_L^*(O,O)/\partial d > 0$, $\partial e_L^*(O,O)/\partial n_H > 0$, $\partial e_L^*(O,O)/\partial n_L < 0$. *Furthermore,* $\partial e_L^*(O,M)/\partial a < 0$, $\partial e_L^*(O,M)/\partial\theta_H > 0$, $\partial e_L^*(O,M)/\partial d > 0$, $\partial e_L^*(O,M)/\partial n_H > 0$, *whereas* $\partial e_L^*(O,M)/\partial n_L < 0$ *only when* $n_H > (g-\theta_L)/(d(1-a)\cdot(\theta_H-\theta_L))$.

When the OEM serves both segments through *Ownership*, it sells the lower-efficiency vehicles (i.e., the vehicles with the higher driving performance) to the high segment and the higher-efficiency vehicles (i.e., the vehicles with the lower driving performance) to the low segment. This is expected as the customers of the high segment value driving performance more and the customers of the low segment value fuel efficiency more. This ranking of efficiencies between the two segments is also true when the OEM finds it optimal to induce the (O, M) equilibrium. In this case, the fuel efficiency of the vehicles provided to the low segment is even higher. That is, car sharing incentivizes producing vehicles of higher fuel efficiency. Although improvements in fuel efficiency are costly, under car sharing such improvements reduce the operating cost that the OEM incurs. Additionally, under car sharing the total production cost is moderated by the pooling effect (i.e., the OEM produces costlier vehicles but fewer of them). Hence, improving the fuel efficiency increases the OEM's effective profit margin.

According to Proposition 1, regardless of whether the OEM optimally induces $(O,\varnothing)$, (O,O), or (O,M), the fuel efficiency (and therefore, the driving performance) of the vehicles sold to the high segment is always the same. This choice is consistent with findings of previous research on product line design, which prescribes that firms offer the efficient product quality (i.e., the product design that maximizes the difference between the customers' valuation and the firm's production cost) to the high valuation segment (Moorthy and Png 1992, Chen 2001).

Proposition 1 also characterizes the effect of customer heterogeneity on the OEM's product line design. The heterogeneity in the market and the information asymmetry stemming from the fact that the OEM cannot observe the preferences of individual customers create potential cannibalization. We define *potential cannibalization* as the profit the OEM foregoes to serve both segments with two distinct mobility options/product designs (i.e., the informational rent extracted by the high segment); see Moorthy and Png

(1992) and Netessine and Taylor (2007). This informational rent increases in the relative appeal of the high segment to the OEM. For instance, larger values of θ_H increase this appeal and, therefore, also increase the potential cannibalization. In this case, to ensure that high-segment customers self-select to the mobility option/product design targeted at them, the OEM decreases the efficiency (i.e., increases the driving performance) of the vehicles sold to the high segment and increases the efficiency (i.e., decreases the driving performance) of the vehicles provided to the low segment (via *Ownership* or *Membership*).

Along these lines, the relative size of the low segment also affects the relative appeal of the high segment. Specifically, larger values of n_L (or smaller values of n_H) decrease this appeal (i.e., the potential cannibalization decreases); for that reason the OEM does not have to further improve the fuel efficiency to avoid cannibalization. That is, for larger values of n_L (or smaller values of n_H) the OEM decreases the efficiency of the vehicles it provides to the low segment. This is always the case under (O, O). However, under (O, M), decreasing the efficiency of the car sharing vehicles erodes the OEM's profit margin by increasing the operating cost. The OEM does so only when there is sufficient population in the high segment to compensate for that.

The effect of customers' use needs and required service level on the OEM's efficiency decisions is also characterized in Proposition 1. Under the *Ownership* option, the use needs d directly moderate the value that customers derive based on the driving performance of the vehicles. Thus, for larger d, the OEM sells vehicles of lower efficiency to the high-segment customers because they value driving performance more, and the OEM sells vehicles of higher efficiency to the low-segment customers because they value fuel efficiency more. Although under (O, M) the low segment does not directly benefit from more fuel efficient products (all else being equal, their utility decreases because of the lower driving performance), the OEM increases the fuel efficiency of the vehicles it dedicates to car sharing because larger values of d increase its total operating cost. Finally, higher service level requirements weaken the pooling effect of car sharing (i.e., they increase the number of vehicles in the car sharing fleet). Hence, to contain the total production cost, the OEM lowers the fuel efficiency of the car sharing vehicles. Next, we characterize the OEM's optimal pricing strategy under each market equilibrium and compare them.

Proposition 2. *The price charged to the high segment under (O, M) is lower than the price charged under $(O, \varnothing)$ but higher than the price charged under (O, O), i.e., $F_H^*(O, \varnothing) > F_H^*(O, M) > F_H^*(O, O) (> F_L^*(O, O))$.*

The previous literature on product line design also prescribes that when offering two products, the firm should decrease the price it charges the high-valuation segment to avoid demand cannibalization (i.e., to avoid having customers of the high-valuation segment choose the product targeted to the low-valuation segment). This is also the case in our context as we find that the selling price to the high segment under (O, M) is lower than the selling price to the high segment under $(O, \varnothing)$. However, when we compare the price charged to the high segment under (O, O) with the price charged under (O, M), we find that in the latter case the OEM sets a higher price. This implies that car sharing attenuates the risk of cannibalization and allows the OEM to extract more surplus from the high segment under (O, M) than under (O, O). The reason is that under (O, M), the OEM invests in higher fuel efficiency (lowering the driving performance of the vehicles it dedicates to car sharing), which decreases the appeal of *Membership* to the high segment. Therefore, in addition to possibly expanding its market coverage, an OEM may want to offer *Membership* to increase its profit through *Ownership*. This finding emphasizes the importance of taking the OEM's perspective and jointly considering the interaction of the *Ownership* and *Membership* mobility options. We continue by evaluating how the OEM's product design strategy affects its ability to comply with the CAFE standards.

4.3. The Effect of the OEM's Decisions on the CAFE Outcomes

The OEM's business model and product design strategy determines the total quantity and fuel efficiency of the vehicles produced. For that reason, it directly affects the average fleet efficiency. The next finding compares the CAFE levels $r(h, l)$, where $h \in \{O\}$ and $l \in \{O, M, \varnothing\}$, that an OEM reaches through the different business models at optimal prices and fuel efficiencies.

Proposition 3. *At the optimal prices and fuel efficiencies, $r(O, O) > r(O, \varnothing)$ and $r(O, M) > r(O, \varnothing)$. Furthermore, there exists $\bar{\theta}_H$ such that $r(O, M) < r(O, O)$ if and only if (iff) $\theta_H > \bar{\theta}_H$.*

Based on Proposition 1, the fuel efficiency of the vehicles sold to the high segment is always the same. Furthermore, the high segment is always served through *Ownership*. Therefore, any changes in the CAFE level reached under the different business models are attributed to serving the low segment (either through *Ownership* or *Membership*). The fuel efficiency of the vehicles sold to the low segment is always higher than the fuel efficiency of the vehicles sold to the high segment (see Proposition 1). For that reason, the OEM always reaches higher CAFE level under (O, O) than under $(O, \varnothing)$.

Proposition 1 also states that the fuel efficiency of the vehicles dedicated to the low segment through car sharing under (O, M) is higher than the fuel efficiency of the vehicles sold to the low segment under (O, O). Proposition 3 reveals that for larger values of θ_H, this higher fuel efficiency does not also translate to higher CAFE levels. OEMs serving customers with higher θ_H face higher potential cannibalization, which they avoid by decreasing the fuel efficiency of the vehicles sold to the high segment and by increasing the fuel efficiency of the vehicles provided (through *Ownership* or *Membership*) to the low segment. In this manner, the mobility option targeted at the low segment is less appealing to the customers of the high segment. Under (O, O), the decrease in the efficiency of the vehicles sold to the high segment is offset by the increase in the efficiency of the vehicles sold to the low segment. However, this is not the case under (O, M). The reason is that the pooling effect of car sharing (i.e., the fact that the OEM serves the low segment with fewer vehicles under (O, M) than under (O, O)) lessens the contribution of these more fuel-efficient vehicles to the fleet average. Next we identify the conditions under which the OEM introduces each business model.

4.4. Optimal Market Strategy: Economic and Environmental Implications

In the benchmark case limited to sales only the OEM optimally induces one of the following equilibria: (i) (O, O) where both segments buy vehicles; (ii) $(O, \varnothing)$ where only the high segment buys vehicles and the low segment relies on its *Outside Option* (we do not consider the $(\varnothing, O)$ equilibrium as it is always dominated by $(O, \varnothing)$ or (O, O)); (iii) $(\varnothing, \varnothing)$ where both segments rely on their *Outside Option*. The OEM decides whether to offer car sharing by comparing the profits under these equilibria with the profit under (O, M), where the high segment buys a vehicle and the low segment chooses car sharing.

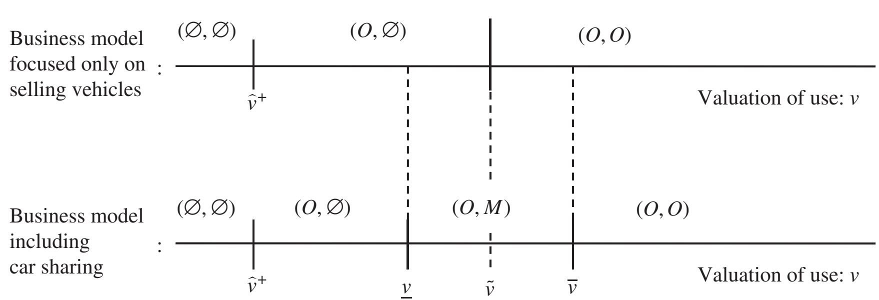
Proposition 4. *If focused on sales only, there exist $\hat{v}$ and $\tilde{v}$ such that the OEM optimally induces the following*: (i) $(\varnothing, \varnothing)$ *when* $v < \hat{v}^+$ (ii) $(O, \varnothing)$ *when* $v \in [\hat{v}^+, \tilde{v})$ *and* (iii) (O, O) *when* $v \geq \tilde{v}$. *With car sharing, there exist* $\underline{v}$ *and* $\bar{v}$ *such that the OEM optimally induces*: (i) $(\varnothing, \varnothing)$ *when* $v < \hat{v}^+$, (ii) $(O, \varnothing)$ *when* $v \in [\hat{v}^+, \underline{v})$, (iii) (O, M) *when* $[\underline{v}, \bar{v}]$ *where* $\tilde{v} \in (\underline{v}, \bar{v})$, *and* (iv) (O, O) *when* $v > \bar{v}$.

Proposition 4 indicates that no business model strategy is universally more appealing to the OEM. Rather, the business model choice can be characterized by the extent to which the customers of each market value vehicle use (see Figure 2). Specifically, in markets with high valuation of vehicle use, the OEM prefers to sell to both segments: Higher valuation of use implies that customers derive higher utility from satisfying their mobility needs per se, as opposed to deriving utility from enjoying the vehicle's driving performance. This makes the effect of product differentiation less important and, effectively diminishes the implications of possible cannibalization, which then allows the OEM to increase its customer base by selling to both segments. This is not the case for markets with low valuation of vehicle use: Here, smaller values of v limit the consumer surplus that the OEM can extract. Furthermore, to appeal to low-segment customers, the OEM must make costly efficiency improvements. In response, the OEM targets only the high segment. Figure 2 shows how the OEM's optimal business model choice changes as a function of the customers' valuation of vehicle use.

In Figure 2 we see that car sharing is not necessarily associated with low valuations of vehicle use, as might be expected due to the fact that customers are not guaranteed to always find a car available. On the contrary, car sharing can be the optimal choice in a medium-valuation market. On the one hand, (O, M) may replace $(O, \varnothing)$ when the valuations of vehicle use are relatively small but not small enough to deter the OEM from pursuing additional volume. On the other hand, (O, M) may replace (O, O) when valuations are relatively large but not large enough to weaken the potential cannibalization.

We now assess the environmental implications of introducing *Membership*. To this end, we calculate the environmental impact generated during the production phase, which depends on the total number of vehicles produced, and during the use phase, which depends on the aggregate vehicle use and the fuel efficiency of the vehicles used. In particular, we define the total environmental impact as $E = \zeta_p$(Total Production Quantity) $+ \zeta_u(e)$(Aggregate Use), where ζ_p is the unit

Figure 2. Market Equilibria



environmental impact due to production and $\zeta_u(e)$ is the unit environmental impact (decreasing in the fuel efficiency e) due to use.

Corollary 1. *If $\nu \in [\underline{\nu}, \tilde{\nu}]$, introducing car sharing increases the OEM's profitability and CAFE level, but also increases its total environmental impact. If $\nu \in (\tilde{\nu}, \bar{\nu}]$, car sharing is a win–win strategy as it increases the OEM's profitability and decreases its environmental impact, but it decreases the OEM's CAFE level when $\theta_H > \bar{\theta}_H$.*

In markets where customers' valuation of use is such that (O, M) replaces $(O, \varnothing)$ (see Figure 2), the environmental impact increases due to the market expansion effect (i.e., because the low segment becomes active through *Membership*). The pooling effect and the fact that the OEM further improves the efficiency of the vehicles dedicated to *Membership* can partially mitigate this increase in the environmental impact, but the net effect is always environmentally negative. On the other hand, if customers' valuation of driving is such that (O, M) replaces (O, O), then the environmental impact always decreases due to the pooling effect (i.e., the number of vehicles required to serve the low segment decreases) and the fact that the use needs of the low segment are satisfied only a fraction of thtime, a (i.e., the aggregate use of the low segment decreases). The higher efficiency of the vehicles dedicated to *Membership* also contributes to the decrease in the environmental impact. Therefore, when $\nu \in (\tilde{\nu}, \bar{\nu}]$, introducing *Membership* is a win–win strategy.

Despite the fact that moving from (O, O) to (O, M) is always environmentally beneficial, OEMs serving customers with $\theta_H > \bar{\theta}_H$ may realize a decrease in their CAFE levels. This misalignment is attributed to the way that the CAFE level is calculated, which is based on the total number of vehicles produced. In other words, the pooling effect of car sharing may actually hinder the OEM's ability to meet the enacted standards because it results in a smaller production quantity. In practice, OEMs are penalized based on the extent to which they do not meet the CAFE standards. Therefore, there may be cases where the transition to a more sustainable business model such as car sharing may be discouraged due to the environmental regulation and, specifically, the way that the CAFE level is calculated.[7] Next we describe the policy implications of this finding.

Proposition 5. *For OEMs serving customers with $\theta_H > \bar{\theta}_H$, there exists $\bar{m} > 1$ such that $r(O, M) \geq r(O, O)$ iff an incentive multiplier $m \geq \bar{m}$ is granted for the compliance calculation of $r(O, M)$. Furthermore, $\partial \bar{m}/\partial \theta_H > 0$, $\partial \bar{m}/\partial d > 0$, and $\partial \bar{m}/\partial n_H > 0$. Additionally, $\partial \bar{m}/\partial g < 0$, $\partial \bar{m}/\partial n_L < 0$, whereas $\partial \bar{m}/\partial a > 0$ iff $n_H < (1-(1-d)n_L(1-a)^2)(g-\theta_L)/((1-a)^2(\theta_H - \theta_L))$.*

One possible way to avoid discouraging OEMs from providing car sharing is for policy makers to offer incentive multipliers. Such multipliers can be granted to OEMs serving markets with $\theta_H > \bar{\theta}_H$ so that each shared car they provide counts as m vehicles in the calculation of the CAFE level. A similar measure is already proposed for advanced technology vehicles (e.g., starting in 2017 each electric vehicle will count as two vehicles; see U.S. EPA 2012) and can incentivize OEMs to offer a business model that is economically and environmentally beneficial.

A multiplier $m \geq \bar{m} > 1$ guarantees that $r(O, M) \geq r(O, O)$. As explained in Proposition 3, the reason that $r(O, M) < r(O, O)$ for $\theta_H > \bar{\theta}_H$ is that, due to the pooling effect of car sharing, the decrease in the efficiency of the vehicles sold to the high segment is not offset by the increase in the efficiency of the vehicles provided through car sharing to the low segment. This is also the case for larger values of θ_H and d, which decrease the efficiency of the vehicles targeted to the high segment and increase the efficiency of those targeted to the low segment (see Proposition 1). A larger high segment (or a smaller low segment) further undermines the contribution of the more efficient vehicles to the calculation of the CAFE level $r(O, M)$. For that reason, $\bar{m}$ increases in n_H and decreases in n_L. The multiplier $\bar{m}$ decreases in g because for larger values of g the OEM improves the efficiency of all the vehicles it produces to contain the total operating cost. Finally, if the size of the high segment is not large enough, then stronger multipliers are needed for higher values of a. This happens despite the fact that a higher service level results in a larger number of car sharing vehicles, which are always more efficient than the vehicles sold to the high segment. As we have seen in Proposition 1, for higher service level requirements the OEM lowers the efficiency of the car sharing vehicles. Hence, although the number of more efficient vehicles that enters into the calculation of $r(O, M)$ increases, the efficiency of these vehicles decreases. The minimum value that $e_L^*(O, M)$ can acquire is $e_L^*(O, O) > e_H^*$ (i.e., $a \to 1$ leads to $e_L^*(O, M) \to e_L^*(O, O) > e_H^*$), which further decreases for smaller values of n_H (see Proposition 1).

We continue by analyzing how the OEM's strategy (and the economic and environmental implications of such a strategy) depends on the characteristics of the market served by the OEM. We have considered the market to be heterogeneous with respect to how much customers value driving performance. The ranking of the average driving performance of different OEMs provided by International Council on Clean Transportation (ICCT) indicates that in practice different OEMs target different market segments. For instance, BMW's average engine power is larger than Volkswagen's, which is larger than Ford's. Hence, in what follows we refer to the OEMs that, all else being equal, serve customers with higher values of θ_H as "higher-end" OEMs.

In our model, we have considered the market to be homogeneous with respect to how much customers value vehicle use v. However, markets with different locations or demographics may be characterized by different v values. Therefore, if for certain OEMs, a strategy is optimal under a wider range of v values, then these OEMs benefit more from such a strategy as they can implement it in more markets. Along these lines, the next proposition summarizes the OEM's optimal equilibrium choice with respect to θ_H.

Proposition 6. *If focused on sales only, the OEM induces $(O,\varnothing)$ for larger values of θ_H (i.e., $\partial\tilde{v}/\partial\theta_H > 0$). With car sharing, the OEM induces (O,M) for larger values of θ_H (i.e., $\partial(\bar{v} - \underline{v})/\partial\theta_H > 0$).*

The first part of Proposition 6 implies that, if focused only on sales, higher-end OEMs prefer to serve only the high segment in more markets than lower-end OEMs. That is, higher-end OEMs benefit more from excluding the low segment and focusing only on the high segment. This is consistent with findings in the previous literature (Moorthy and Png 1992, Netessine and Taylor 2007), and is attributed to the fact that a higher valuation θ_H increases potential cannibalization. In such cases, to sell to both segments, the OEM must significantly decrease the price it charges the high segment; for that reason it induces $(O,\varnothing)$ instead.

The issue of cannibalization is also responsible for the fact that higher-end OEMs offer car sharing in more markets than lower-end OEMs. This implies that car sharing benefits higher-end OEMs more than lower-end OEMs. In particular, *Membership* allows for a better separation of the two customer segments and helps minimize potential cannibalization. This is due to the cost savings of the pooling effect, which enables the OEM to choose higher-efficiency vehicles (i.e., vehicles with lower driving performance). By providing these higher-efficiency vehicles to the low segment, the OEM discourages the high segment from relinquishing *Ownership* for *Membership*. When switching from $(O,\varnothing)$ to (O,M), the increase in profitability is attributed to the market expansion effect (i.e., the OEM benefits from expanding to the low segment), and when switching from (O,O), the increase in profitability is attributed to the pooling effect (i.e., the needs of the low segment are met through fewer vehicles) and the higher price charged to the high segment (see Proposition 1). Our findings in Proposition 6 may help explain why higher-end OEMs like BMW and Daimler have been particularly active in introducing car sharing programs.

4.5. The Effect of CAFE Regulation on the OEM's Strategy

To better understand the implications of the CAFE standards, we investigate the optimal pricing and business model strategy when the OEM is constrained by the enacted regulation (i.e., when the OEM does not meet the standards at its unconstrained optimal decisions).

Proposition 7. *When the CAFE standard is binding at optimality, $\partial F_H{}^*(O,\varnothing)/\partial R < 0$, $\partial F_H{}^*(O,O)/\partial R > 0$, and $\partial F_L{}^*(O,O)/\partial R > 0$. Furthermore, $\partial p^*/\partial R < 0$, whereas $\partial F_H{}^*(O,M)/\partial R < 0$ iff $a < (\theta_H - g)/(g - \theta_L)$.*

Regardless of the market equilibrium, stricter regulation forces the OEM to increase the fuel efficiency of its vehicles beyond the most profitable levels. It may first appear that such an increase affects the higher-end OEMs more since it comes at the expense of driving performance, implying that a decrease in the selling prices may be necessary to maintain the appeal to the performance-sensitive customers. However, we find that this may not be always true. Under $(O,\varnothing)$, the OEM indeed lowers the selling price due to the increase in the fuel efficiency of its vehicles. By contrast, under (O,O), we find that the OEM increases the fuel efficiency and the selling prices of its vehicles. In this case, the low segment benefits from the higher efficiency, which allows the OEM to charge a higher price and extract the consumer surplus. Furthermore, although the driving performance of the cars sold to the high segment is lower under more aggressive CAFE standards, the even higher fuel efficiency of the vehicles sold to the low segment makes the customers of the high segment less willing to switch, allowing the OEM to charge them a higher price.

Under (O,M), the per-unit-of-time price of car sharing decreases. Even though the low-segment customers value fuel efficiency more, under car sharing they do not derive an immediate additional benefit from using a higher-efficiency vehicle. If anything, they derive a smaller benefit due to the lower driving performance of the vehicles. Finally, a higher service level renders car sharing more appealing to customers. For that reason, under (O,M) and larger values of a, the OEM typically decreases the selling price to discourage high-segment customers from relinquishing *Ownership* for *Membership*. Under more aggressive CAFE standards, however, this appeal is moderated by the higher fuel efficiency (i.e., lower driving performance) of the vehicles used for car sharing and, thus, the OEM does not lower its selling price to the high segment.

Proposition 8. *If the OEM is focused on sales only and the CAFE standard is binding at optimality, $\partial\tilde{v}/\partial R < 0$ for $R \in [r(O,O), e_L^*(O,O))$ and $\partial\tilde{v}/\partial R \geq 0$ for $R \geq e_L^*(O,O)$. With car sharing, if the CAFE standard is binding at optimality, $\partial(\bar{v} - \underline{v})/\partial R > 0$.*

In the case of selling only, the effect of regulation on the optimal business model choice depends on how aggressive the CAFE standards are. If the standards exceed the CAFE level that the OEM achieves under (O, O) but are less than the fuel efficiency of the vehicles sold to the low segment, then the OEM reacts to stricter standards by replacing $(O, \varnothing)$ with (O, O). By contrast, if the CAFE standards are even more aggressive and exceed the efficiency of the vehicles sold to the low segment, then the OEM reacts by replacing (O, O) with $(O, \varnothing)$. This happens despite the fact that under (O, O) the OEM increases its selling prices and sells more vehicles of higher driving performance (i.e., lower efficiency) to the high segment than under $(O, \varnothing)$. The reason is that by selling to only part of the market (i.e., only the high segment versus both segments), the OEM limits the increase in the total production cost due to the higher fuel efficiency. Along similar lines, with car sharing more aggressive CAFE standards always incentivize the OEM to induce (O, M) in more markets because the pooling effect attenuates the cost implications of producing higher-efficiency vehicles. Therefore, including car sharing can be a good strategy to better absorb the cost implications of abiding by the CAFE standards.

5. Conclusions

This work is motivated by the fact that recently, major OEMs such as Daimler and BMW have included car sharing in their business models. The overall characteristics of the car sharing programs provided by these OEMs have been the same: (i) customers pay only for the amount of time they use the vehicles and (ii) the same vehicle can be used by many customers at different periods of time, creating a pooling effect. However, the strategies on what type of vehicles to offer through car sharing are still emerging. For instance, Daimler only offers its highest efficiency Smart fortwo model while BMW offers a wider range of models concentrated on the higher end of their efficiency portfolio. The OEM's choice of fuel efficiency is particularly important because (i) it may come at the expense of driving performance, making the vehicles less appealing to customers, but it can also (ii) improve the OEM's ability to comply with increasingly strict CAFE regulation.

In this paper, we study the interaction between business model choice, product line design, and environmental regulation. Specifically, we determine the OEM's optimal business model and product line by balancing the trade-off between driving performance and fuel efficiency in the presence of CAFE regulation. Our analysis generates insights not identified by previous research.

We find that pooling enables the OEM to increase the fuel efficiency of the vehicles it provides through car sharing. This is in agreement with the practices of Daimler and BMW who provide higher-efficiency as opposed to higher-driving performance vehicles. This efficiency choice attenuates the effect of cannibalization and allows the OEM to maintain the driving performance of the vehicles it sells to the higher-end of the market but at a higher price and, therefore, higher profit. Higher-end OEMs face stronger potential cannibalization; for that reason, they benefit more from including car sharing in their business models. This is an important finding because it may help explain why higher-end OEMs such as Daimler and BMW have been particularly active and taken the lead in introducing car sharing programs. To our knowledge, ours is the first study to characterize the OEM's benefits from offering car sharing, identify the type of OEMs that benefit most, and determine how car sharing affects the OEM's product line design.

Contrary to some recent claims (Zipcar 2015), we find that introducing car sharing does not always benefit the environment. The reason is that car sharing may attract customers who would otherwise resort to alternative modes of transportation (e.g., public transportation) resulting in a higher production volume and, therefore, increased environmental impact. Even in cases where providing car sharing benefits the environment by decreasing the environmental impact, we find that the pooling effect of car sharing may actually decrease the OEM's CAFE level. Such a decrease may disincentivize OEMs from adopting a car sharing business model despite it being economically and environmentally superior. We show that this issue can be addressed with the use of incentive multipliers that count each shared vehicle as more than one in the compliance calculation of CAFE. Finally, car sharing can be a good strategy to mitigate the loss in profitability resulting from the enactment of more aggressive standards for an OEM's CAFE level. To our knowledge, this is the first study to identify and characterize the connection between the OEM's incentive to offer car sharing and existing environmental regulation in the automotive industry.

Our model operationalizes the pooling effect of car sharing through a queuing approximation that determines the number of vehicles required for the OEM to meet a certain service level a, which we assumed to be exogenous. Via numerical optimization, we have verified that our findings are robust to endogenizing the service level. For instance, as is the case with exogenous a, the OEM provides vehicles of higher fuel efficiency through car sharing, the pooling effect may decrease the OEM's CAFE level, and car sharing remains the optimal choice in a medium-valuation market.

In addition, we provide insights on the effect of the different parameters of our model on the OEM's optimal choice of service level. Specifically, we find that higher-end OEMs choose a lower service level. Because these OEMs face greater potential cannibalization, they decrease the service level to discourage high-segment customers from switching to car sharing. The optimal service level is lower for larger production costs because the OEM wants to contain the total production cost. The relationship between service level and customers' valuation of vehicle use is complementary. For a given price and fuel efficiency, they both increase customers' utility and, as an extension, the consumer surplus that the OEM can extract. This effect also incentivizes the OEM to increase the service level with respect to customers' use needs, despite the fact that larger vehicle use increases the total operating and production cost of car sharing. Changes in the operating cost do not affect the choice of service level because the OEM reacts to different operating costs mainly through different vehicle designs (i.e., through different fuel efficiencies).

To obtain first-order insights, our analysis was conducted in the absence of competition. Although we expect the presence of competition to further increase the environmental impact due to higher market expansion resulting from lower prices, it may also decrease the OEM's benefit from offering car sharing. Competition may also give rise to several nuanced effects. For instance, the fact that the OEM has access to cheaper raw material and production (e.g., unsold inventory) can create a pricing advantage over any third-party provider. On the other hand, a third-party provider has the advantage of sourcing from multiple OEMs, which may be appealing to customers seeking variety.

Furthermore, an OEM may actually benefit from the presence of third-party providers because customers can use their services as a last resort option when they cannot find a vehicle through the OEM's car sharing program. This benefit may be particularly strong for higher-end OEMs. The reason is that, all else being equal, customers may prefer to join the programs of higher-end OEMs in the first place, so they can meet their transportation needs using higher-end vehicles. Future research that incorporates competitive pressure from other OEMs or third-party providers may also uncover valuable insights.

Similarly, our analysis was conducted in the absence of channel frictions. In addition to determining whether to offer car sharing, the OEM may also evaluate different supply chain structures. For instance, an OEM may choose to sell vehicles through a retailer and offer car sharing through a direct channel or sell vehicles and offer car sharing through the same retailer. This is a promising direction of future research.

Finally, we have assumed that the customers' valuation of vehicle use and needs are the same regardless of whether they choose car ownership or car sharing. In practice, this may not be true because customers may experience several forms of inconvenience when meeting their transportation needs through car sharing. Such forms of inconvenience can be the anxiety about potentially not finding a vehicle available when needed, the need to budget extra commute time to walk to and from the parking lot, feeling pressed to curtail vehicle use since payment is directly linked to the duration of use, and, the lack of ownership pride. We expect that, as the model of car sharing matures and car sharing networks continue to expand in more geographic areas, the importance of some of these factors will diminish over time. Nevertheless, a more detailed treatment of such inconvenience factors or intangible benefits such as the satisfaction of adopting green practices presents a promising direction of future research that can provide additional insights on the appeal of car sharing to customers.

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Endnotes

[1] Note that Daimler was the first provider to reach $1 million members (in December 2014) despite the fact that it entered the car sharing business almost 10 years after third-party providers such as Flexcar and Zipcar introduced the first car sharing programs. Zipcar (merged with Flexcar in 2007) reached the same milestone in September 2016 (Zipcar 2016). Today, Zipcar is the main third-party car sharing provider. Other third-party providers, with smaller membership bases are Enterprise CarShare and City CarShare; for a comprehensive list see Navigant Research (2013).

[2] Because of differences in the calculation methods of the fuel efficiencies, the target of 54.5 miles per gallon does not represent the window sticker value. Rather, it is estimated that it corresponds to 36 miles per gallon (city and highway combined) on a window sticker; see Edmunds and O'Dell (2013).

[3] Not all OEMs may be limited by this trade-off. For instance, Tesla's P85 version of the Model S electric vehicle can reach 60 miles per hour in 3.9 seconds. Our focus is mainstream technologies and OEMs that are subject to the driving performance versus fuel efficiency trade-off.

[4] For a recent treatment of the availability issues in bike-sharing systems, see Kabra et al. (2016).

[5] Relaxing this assumption would result in both segments being served through more than one mobility option. Although this would complicate the analysis and change the specific pricing decisions, we do not expect it would affect the directionality of our main findings or the key insights emerging from the analysis.

[6] It is straightforward to show that the use of a weighted average instead of a harmonic mean does not affect the relative comparisons of the different CAFE levels associated with the OEM's efficiency choices under different equilibria. If, all else being equal, the CAFE level under one equilibrium is higher/lower than the CAFE level under a different equilibrium, the same will be true regardless of whether the CAFE levels are calculated using a harmonic mean or weighted average.

[7] As noted earlier, our model focuses on customers whose driving needs do not force them to rule out car sharing as an option. Our finding that CAFE standards may hinder the adoption of car sharing

(due to the decrease in the CAFE level) does not change if we include the broader market. The only difference is in the magnitude of the effect, which will be smaller if the car sharing market represents a smaller portion of the total market.

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