To Sell and to Provide?
The Economic and Environmental Implications of the Auto Manufacturer’s Involvement in the Car Sharing Business

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Motivated by the involvement of Daimler and BMW in the car sharing business we consider an OEM who contemplates introducing a car sharing program. The OEM designs its product line by accounting for the trade-off between driving performance and fuel efficiency. Customers have different valuations of driving performance and decide whether to buy, join car sharing, or rely on their outside option. Car sharing can increase the profit from selling. This happens when the OEM prefers to serve the lower-end customers through car sharing and the higher-end through selling. In this case, car sharing increases the efficiency of the vehicles used for the lower-end, and the price charged to the higher-end customers. This is more pronounced for higher-end OEMs, which may help explain Daimler’s and BMW’s involvement in car sharing. Despite the higher efficiency, car sharing may lower the OEM’s Corporate Average Fuel Economy (CAFE) level even when it increases profit and decreases environmental impact. CAFE levels better reflect the environmental benefits of car sharing when they are based on the number of customers served and not the production volume. Finally, if anticipating aggressive CAFE standards, OEMs may include car sharing to better absorb the increase in the production cost.

Key words: car sharing; sustainable transportation; 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 while gas, maintenance, and insurance are included in the hourly price. In this manner, car sharing transforms the fixed
costs associated with the ownership of a vehicle (e.g., purchase cost, depreciation, insurance) to a variable cost that depends on vehicle usage. Zipcar, founded in 1999, is the largest for-profit car sharing provider with over 900,000 members across the U.S., Canada, and Europe (Zipcar 2016b). According to Shaheen and Cohen (2015) the number of car sharing members in the U.S. has increased from 52K in 2004 to 1.28M in 2015. Navigant Research (2013) estimates that by 2020 the global car sharing market will be worth $6.2B in revenues.

Although car sharing programs are typically associated with independent providers like Zipcar, several auto manufacturers have recently started introducing car sharing schemes. Daimler, for example, operates a car sharing program in several cities in the U.S. and Europe (CAR2GO 2016), while BMW operated a similar scheme in San Francisco (DriveNow 2015) with the city of Seattle to follow soon (The Seattle Times 2015). In addition, Peugeot, Volkswagen, and Ford operate car sharing programs in several European cities (Mu 2016, Quicar 2016, Ford 2015). Recently, GM started testing its own car sharing program in the city of Ann Arbor (The Wall Street Journal 2016). Such moves are indicative of a broader transformation that auto manufacturers are undergoing to become mobility companies (Fortune 2015).

Nevertheless, the economic benefits of the auto manufacturers’ strategy of introducing car sharing programs are not clear. On the one hand, offering products under membership-based schemes may cannibalize the demand from customers who otherwise would purchase vehicles and, therefore, may decrease the manufacturers’ profitability. For example, Zipcar estimates that in the absence of car sharing, one out of four of their members would have bought a car (Zipcar 2016a). On the other hand, car sharing can benefit the auto manufacturers (henceforth “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.

In addition to the increasing interest of manufacturers in providing car sharing programs, the U.S. Environmental Protection Agency has categorized car sharing as a top-ten, high-potential “green” business model (U.S. EPA 2009). Along these lines, car sharing providers
often promote their programs by highlighting their environmental superiority over the more conventional practice of selling cars. For instance, Zipcar claims that each shared car covers the transportation needs of 40 members (Zipcar 2016a). Navigant Research (2013) also estimates that each shared car takes approximately 5 to 11 vehicles off the road (Shaheen and Cohen 2015 estimate this 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.

Improving environmental performance may 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. 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 miles per gallon (U.S. Department of Transportation 2012). Surveying the average fleet efficiency of different OEMs reveals that BMW and Daimler, along with other “high-end” OEMs like 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. Besides the obvious cost implications that 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 (Wong 2001). Car sharing offers advantages that may make it more attractive for these OEMs to produce vehicles of higher efficiency, and therefore, facilitate their efforts to meet the CAFE standards. 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

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1 Due to 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 (2013).
pronounced as an OEM could possibly 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.

In this paper, we consider an OEM who contemplates introducing car sharing to complement its traditional sales business model. The market comprises customers who differ with respect to how much they value vehicle driving performance (e.g., acceleration). 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). Accounting for this trade-off\(^2\) 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 employ 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 both 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 decision of the OEM 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.

\(^2\) Not all OEMs may be limited by this trade-off. For instance, Tesla’s P85 version of the Model S electric vehicle is able to reach 60 miles per hour in 3.9 seconds. Our focus is on mainstream technologies and OEMs that are subject to the driving performance versus fuel efficiency trade-off.
With respect to the environmental regulation, our findings suggest that OEMs offering car sharing should be granted incentive multipliers for each shared vehicle they provide. 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 both 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 their 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 servicing business models (Rothenberg 2007), in which the use, rather than the 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 servicing 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 (2015), who analyze the effect of the structural characteristics of servicing business models on overall environmental performance. However, they do not consider a product line
and, therefore, they do not analyze the effect of environmental regulation such as CAFE standards on the OEM’s strategy. By doing so, we find that including car sharing may 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 both 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 an adoption. Although these papers share conceptual similarities, their scope is very different. Our focus is on product-market business models, whereas their focus is on post-sales operating models to service purchased products (namely, 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 model of car sharing, He et al. (2015) 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, the 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 both the product design and the business model choice, we generate new insights regarding 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). In 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 like BMW and Daimler have been 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 2015), product introduction (Plambeck and Wang 2009), product design (Chen 2001, Subramanian et al. 2009, Kraft et al. 2013, Esenduran and Kemahhoğlu-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), as it 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 Corporate Average Fuel Economy (CAFE) standard (NHTSA 2015) whereby the U.S. Department of Transportation holds automotive OEMs accountable for meeting increasingly aggressive standards (The Wall Street Journal 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 both 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). ConsumerReports (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). Similar conclusions are drawn by Berry et al. (1995). More recently, Guajardo et al. (2015) 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 \( v \in [0, 1] \) to denote the vehicle driving performance and we explicitly account for the inherent trade-off between driving performance and fuel efficiency (Wong 2001). To do so in an analytically tractable manner we follow Chen (2001) and assume that \( v = 1 - e \), where \( e \in [0, 1] \) is the fuel efficiency. Hence, by determining \( v \) 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 usage 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, Businessweek 2013). Thus, we make \( a \) exogenous in our model. Similarly, in addition to the usage fee, some car sharing providers may charge members a fixed fee to join. For instance, Zipcar charges $70 per year, whereas Car2Go charges 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 has the potential to 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

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3 For a recent treatment of the availability issues in bike-sharing systems, see Kabra et al. (2015).
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 choose to cover their transportation needs by choosing a product design and mobility option $j \in \{O, M, \emptyset\}$, where $O$ stands for Ownership, $M$ for Membership, and $\emptyset$ 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 $\theta_H$, and that of the segment $L$ customers is $\theta_L$, 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 a dense and centralized population, 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 serve similar (e.g., shopping and social/recreational) purposes.\footnote{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.} In particular, we denote by $d$ the customers’ transportation use 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 $\nu$ 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 $\nu$. For example, college students are relatively homogeneous in their vehicle usage 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 public transportation network). In practice, car sharing prices may vary across markets, and even across neighborhoods, reflecting local market characteristics. Such market-by-market positioning of the Membership offering is beyond the scope of our paper but 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 $U^O_i(e, F) = d\left(\nu + \theta_i v - g (1 - e)\right) - F$. The base utility $d\nu$ that customers derive from satisfying their mobility needs (e.g., from running errands) is augmented by $d\theta_i v$. That is, between two customers with the same valuation of performance $\theta$, 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 $v = 1 - e$, the utility can be rewritten as:

$$U^O_i(e, F) = d\left(\nu + (\theta_i - g) (1 - e)\right) - F.$$ 

It is clear that improvements in fuel efficiency positively contribute to $U^O_i$ 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 \( U_i^M(e,p) = ad(\nu + \theta_i \nu - p) \). Similar to the Ownership case, the customers’ utility depends on the extent of the vehicle usage 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., \( U_i^\emptyset = 0 \)). Given that \( v = 1 - e \), the utility can be rewritten as:

\[
U_i^M(e,p) = ad\left(\nu + \theta_i (1 - e) - p\right).
\]

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 like 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. 2015), in which case this assumption is even more applicable.

### 3.2. The OEM’s Problem

We consider markets where the OEM is already present either 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 \((O,\emptyset)\) equilibrium). In order 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, 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. 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 \( v \) and \( e \), respectively. For that reason, we assume that the
Table 1  Notation, \( i \in \{H,L\} \).

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<thead>
<tr>
<th>Parameters</th>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>( \theta_i )</td>
<td>Valuation of driving performance.</td>
<td></td>
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<tr>
<td>( v = 1 - e )</td>
<td>Driving performance.</td>
<td></td>
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<tr>
<td>( d \in (0,1) )</td>
<td>Customers’ vehicle usage need.</td>
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<tr>
<td>( \nu )</td>
<td>Valuation of vehicle usage.</td>
<td></td>
</tr>
<tr>
<td>( n_i )</td>
<td>Size of customer segment ( i ).</td>
<td></td>
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<tr>
<td>( a \in (0,1) )</td>
<td>Service level (vehicle availability) under Membership.</td>
<td></td>
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<tr>
<td>( S(a) )</td>
<td>Number of vehicles that achieve an availability level ( a ).</td>
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<tr>
<td>( g )</td>
<td>Vehicle operating cost.</td>
<td></td>
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<tr>
<td>( c_v )</td>
<td>Unit production cost of driving performance.</td>
<td></td>
</tr>
<tr>
<td>( c_e )</td>
<td>Unit production cost of fuel efficiency.</td>
<td></td>
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<tr>
<td>( r \in [0,1] )</td>
<td>OEM’s CAFE level.</td>
<td></td>
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<tr>
<td>( R \in [0,1] )</td>
<td>CAFE standard.</td>
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Decision Variables | Symbol | Definition |
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<tr>
<td>Pricing:</td>
<td>( F )</td>
<td>Selling price.</td>
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<tr>
<td></td>
<td>( p )</td>
<td>Per-unit-of-time price.</td>
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<tr>
<td>Product Design:</td>
<td>( e \in [0,1] )</td>
<td>Vehicle fuel efficiency.</td>
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The unit production cost of a vehicle with \( v \) and \( e \) levels is given by \( c_v v^2 + c_e e^2 \), where \( c_v, c_e > 0 \) (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:

\[
\Pi_i^O (F, e) = \left( F - c_v v^2 - c_e e^2 \right) n_i = \left( F - c_v (1 - e)^2 - c_e e^2 \right) n_i,
\]

where \( n_i \) is the size of segment \( i \).

The profit that the OEM appropriates from covering the mobility needs of segment \( i \) through Membership at a reservation rate \( p \), using vehicles of fuel efficiency \( e \) is \( \Pi_i^M (p, e) = a(p - g(1 - e))n_id - (c_v v^2 + c_e e^2) S(a) \). 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 §4. For the fraction of time \( a \) that customers find a vehicle available, the OEM gains a revenue \( pn_id \), where \( n_id \) is the aggregate vehicle usage of segment \( i \). However, for the same fraction of time, the OEM incurs a total operating cost of \( g(1 - e)n_id \), which decreases in the vehicle’s fuel efficiency. Similar to the case of Ownership, the total production cost depends on the marginal costs \( c_v \) and \( c_e \) as well as the driving performance \( v = 1 - e \) and fuel efficiency \( e \) except that now the total number of vehicles is \( S(a) (\leq n_i) \). Therefore, the OEM’s profit under car sharing is:

\[
\Pi_i^M (p, e) = a\left(p - g(1 - e)\right)n_id - \left(c_v (1 - e)^2 + c_e e^2\right) S(a).
\]

Having introduced \( \Pi_i^O \) and \( \Pi_i^M \), we next formulate the OEM’s problem of maximizing the total profit from each of the \((O,\emptyset)\), \((O,O)\), and \((O,M)\) equilibria. The OEM cannot
directly observe the valuations of each customer. Due to 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 \textit{Ownership} option is targeted at the High segment and the \textit{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 \textit{Ownership} and the Low segment to choose \textit{Membership}:

\[
\Pi^*(O, M) = \max_{e_H, e_L, F, p} \Pi(O, M)(e_H, e_L, F, p) = \Pi^O_H(F, e_H) + \Pi^M_L(p, e_L)
\]

\[
s.t \quad d\left(\nu + (\theta_H - g) (1 - e_H)\right) - F \geq 0 \quad (IR^H_O)
\]

\[
ad\left(\nu + \theta_L (1 - e_L) - p\right) \geq 0 \quad (IR^L_M)
\]

\[
d\left(\nu + (\theta_H - g) (1 - e_H)\right) - F \geq ad\left(\nu + \theta_H (1 - e_L) - p\right) \quad (IC^H_O)
\]

\[
ad\left(\nu + \theta_L (1 - e_L) - p\right) \geq d\left(\nu + (\theta_L - g) (1 - e_H)\right) - F \quad (IC^L_M)
\]

The individual rationality constraints \(IR^H_O\) and \(IR^L_M\) ensure that the customers of the High and Low segments benefit from meeting their transportation needs through \textit{Ownership} and \textit{Membership}, respectively. The incentive compatibility constraints \(IC^H_O\) and \(IC^L_M\) ensure that the High segment prefers \textit{Ownership} over \textit{Membership} and the Low segment prefers \textit{Membership} over \textit{Ownership}, respectively.

Under \((O, \emptyset)\) the OEM only sells vehicles and determines the efficiency \(e_H^*\) and price \(F^*\) that induce i) the High segment to choose \textit{Ownership} over the \textit{Outside Option} and ii) the Low segment to choose the \textit{Outside Option} over \textit{Ownership}:

\[
\Pi^*(O, \emptyset) = \max_{e_H, F} \Pi(O, \emptyset)(e_H, F) = \Pi^O_H(F, e_H)
\]

\[
s.t \quad d\left(\nu + (1 - e_H) (\theta_H - g)\right) - F \geq 0 \quad (IR^H_O)
\]

\[
d\left(\nu + (1 - e_H) (\theta_L - g)\right) - F < 0. \quad (IR^L_O)
\]

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:

\[
\Pi^*_\{O,O\} = \max_{e_H + e_L, F_H, F_L} \Pi_{\{O,O\}}(e_H, e_L, F_H, F_L) = \Pi^O_H(F_H, e_H) + \Pi^O_L(F_L, e_L) \\
\text{s.t.} \quad d\left(\nu + (1 - e_H)(\theta_H - g)\right) - F_H \geq 0 \\
\quad \quad \quad d\left(\nu + (1 - e_L)(\theta_L - g)\right) - F_L \geq 0 \\
\quad \quad \quad d\left(\nu + (1 - e_H)(\theta_H - g)\right) - F_H \geq d\left(\nu + (1 - e_L)(\theta_L - g)\right) - F_L \\
\quad \quad \quad d\left(\nu + (1 - e_L)(\theta_L - g)\right) - F_L \geq d\left(\nu + (1 - e_H)(\theta_H - g)\right) - F_H.
\]

Similar to Chen (2001) and without loss of generality, in the rest of the analysis we assume values of \(c_x\) and \(c_e\) such that that the optimal fuel efficiency levels lie in the interior \((0, 1)\) under all equilibria. The OEM calculates the optima of the maximization problems and chooses the one that results in the most profitable market equilibrium. That is, \(\{h^*, l^*\} = \arg \max \{\Pi^*_{\{h,l\}} : \Pi^*_{\{O,M\}}, \Pi^*_{\{O,O\}}, \Pi^*_O, \Pi^*_{} = 0\}\).

### 3.3. Modeling CAFE Standards

The maximization problems formulated above do not account for the fact that the OEM’s CAFE level needs to satisfy the 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 the OEM’s CAFE level is given by the harmonic mean \(r = \frac{n_A + n_B}{e_A + e_B}\). 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 \(r = \frac{n_A}{n_A + n_B} e_A + \frac{n_B}{n_A + n_B} e_B\).

\(^5\) Along these lines, in our model the OEM determines the optimal efficiencies and prices that, in addition to the individual rationality and incentive compatibility constraints, also satisfy: i) \(\frac{n_H}{n_H + n_L} e_H + \frac{n_L}{n_H + n_L} e_L \geq R\) under the \((O,M)\) equilibrium, ii) \(\frac{n_H}{n_H + n_L} e_H + \frac{n_L}{n_H + n_L} e_L \geq R\) under the \((O,O)\) equilibrium, and iii) \(e_H \geq R\) under the \((O,\emptyset)\) equilibrium.

\(^5\) 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 through the use of a harmonic mean or weighted average.
4. Analysis and Results

In what follows 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 the enactment of environmental regulation. When comparing across different equilibria we utilize the notation \((h, l)\) with \(h \in \{O\}\) and \(l \in \{O, M, \emptyset\}\). 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 relegated to the Appendix.


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 either 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. Thus, to determine the fleet size that achieves a given service level \(a\), we model Membership as a two-node closed queueing network and draw on the fixed population mean (FPM) approximation developed in Whitt (1984).

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

In the Appendix we provide the technical details regarding the development of the approximation. The second term \(an_id\) in \(S(a)\) represents the number of vehicles required to meet a service level \(a\) when customers’ requests do not overlap. Specifically, \(n_id\) is the aggregate vehicle usage 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 little as \(an_id\) vehicles. The first term \(\frac{a}{1-a}\) 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 it does not account for capacity allocation issues (e.g., fleet rebalancing) across different locations within the same market. Such issues are outside the scope of this paper. For an excellent treatment of such operational considerations, see He et al. (2015).

In what follows we characterize the OEM’s pricing and product design strategy.
4.2. Product Line Decisions: Optimal Pricing and Fuel Efficiency

The OEM cannot observe the preferences $\theta_H$ and $\theta_L$ of individual customers and for that reason 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 $n_L > \frac{1}{(1-d)(1-a)}$ because unless this condition holds the $(O,M)$ equilibrium is always dominated (we elaborate in the Appendix).

Proposition 1. $e_H^*(O,\emptyset) = e_H^*(O,O) = e_H^*(O,M) = e_H^*$ and $e_L^*(O,M) > e_L^*(O,O) > e_L^*$. Additionally, $\partial e_H^*/\partial \theta_H < 0$, $\partial e_H^*/\partial d < 0$, whereas $\partial e_L^*(O,O)/\partial \theta_H > 0$, $\partial e_L^*(O,O)/\partial d > 0$, $\partial e_L^*(O,O)/\partial n_L < 0$. Furthermore, $\partial e_L^*(O,M)/\partial a < 0$, $\partial e_L^*(O,M)/\partial \theta_H > 0$, $\partial e_L^*(O,M)/\partial d > 0$, whereas $\partial e_L^*(O,M)/\partial n_L < 0$ only when $n_H > \frac{g-\theta_L}{d(1-a)(\theta_H-\theta_L)}$.

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 the 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.

Regardless of whether the OEM optimally induces $(O,\emptyset)$, $(O,O)$, 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).
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 in order 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 $\theta_H$ increase this appeal and, therefore, also increase the potential cannibalization. In this case, in order to ensure that the customers of the High segment self-select to the mobility option/product design targeted at them, the OEM both 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 size of the Low segment also affects the relative appeal of the High segment. Specifically, larger values of $n_L$ decrease this appeal (i.e., the potential cannibalization decreases) and for that reason the OEM does not have to further improve the fuel efficiency in order to avoid cannibalization. That is, for larger values of $n_L$ 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.

Under the Ownership option, the usage 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 customers of the High segment because they value driving performance more, and the OEM sells vehicles of higher efficiency to the customers of the Low segment 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 actually 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, in order 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.

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 $(O, \emptyset)$. 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 both 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 that an OEM reaches through the different business models at the optimal prices and fuel efficiencies.

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

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) and for that reason, the OEM always reaches higher CAFE level under \((O,O)\) than under \((O,\emptyset)\).

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 \(\theta_H\), this higher fuel efficiency does not also translate to higher CAFE levels. OEMs serving customers with higher \(\theta_H\) 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 \textit{Ownership} or \textit{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. In what follows 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) \((O,\emptyset)\) where only the High segment buys vehicles and the Low segment relies on its \textit{Outside Option}; \((O,\emptyset)\) always dominates \((\emptyset,O)\), iii) \((\emptyset,\emptyset)\) where both segments rely on their \textit{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, \(\exists \hat{\nu} \text{ and } \tilde{\nu} \) such that the OEM optimally induces: i) \((\emptyset,\emptyset)\) when \(\nu < \hat{\nu}^+\), ii) \((O,\emptyset)\) when \(\nu \in [\hat{\nu}^+,\tilde{\nu})\) and iii) \((O,O)\) when \(\nu \geq \tilde{\nu}\). With car sharing, \(\exists \nu \text{ and } \tilde{\nu} \) such that the OEM optimally induces: i) \((\emptyset,\emptyset)\) when \(\nu < \hat{\nu}^+\), ii) \((O,\emptyset)\) when \(\nu \in [\hat{\nu}^+,[\nu)\), iii) \((O,M)\) when \([\nu,\tilde{\nu}]\) where \(\nu \in (\nu,\tilde{\nu})\), and iv) \((O,O)\) when \(\nu > \tilde{\nu}\).

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 1). 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 $\nu$ limit the consumer surplus that the OEM can extract. Furthermore, in order to appeal to the customers of the Low segment, the OEM must make costly efficiency improvements. In response, the OEM targets only the High segment. Figure 1 shows how the OEM’s optimal business model choice changes as a function of the customers’ valuation of vehicle use.

**Figure 1** Market equilibria.

<table>
<thead>
<tr>
<th>Business model focused only on selling vehicles</th>
<th>Valuation of use: $\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(O,\emptyset)$</td>
<td>$\nu^*$</td>
</tr>
<tr>
<td>$(O,\emptyset)$</td>
<td>$\nu^*$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Business model including car sharing</th>
<th>Valuation of use: $\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(O,\emptyset)$</td>
<td>$\nu^*$</td>
</tr>
<tr>
<td>$(O,\emptyset)$</td>
<td>$\nu^*$</td>
</tr>
<tr>
<td>$(O,M)$</td>
<td>$\nu^*$</td>
</tr>
<tr>
<td>$(O,O)$</td>
<td>$\nu^*$</td>
</tr>
</tbody>
</table>

Specifically, in Figure 1 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 $(O,\emptyset)$ when the valuations of vehicle usage 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 usage and the fuel efficiency of the vehicles used. In particular, we define the total environmental impact as $E = \zeta_p(\text{Total Production Quantity}) +$
\[ \zeta_u(e) \text{ (Aggregate Usage), where } \zeta_p \text{ is the unit environmental impact due to production and } \zeta_u(e) \text{ is the unit environmental impact (decreasing in the fuel efficiency } e) \text{ due to use.} \]

**Corollary 1.** If \( \nu \in [\nu, \tilde{\nu}] \), introducing car sharing increases the OEM’s profitability but also 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 \( \theta_H > \bar{\theta}_H \). If the OEM’s CAFE level is calculated based on the number of customers served (and not on the total number of vehicles produced), then it always improves under car sharing.

In markets where customers’ valuation of use is such that \((O,M)\) replaces \((O,\emptyset)\) (see Figure 1), 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 both the pooling effect (i.e., the number of vehicles required to serve the Low segment decreases) and the fact that the usage needs of the Low segment are satisfied only a fraction of the time, \( a \) (i.e., the aggregate usage 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, higher-end OEMs 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 products sold as opposed to the total number of customers served. In other words, the pooling effect of Membership may actually hinder the OEM’s ability to meet the enacted standards. 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. This finding suggests that for each shared car, incentive multipliers should be granted similar to those currently proposed for advanced technology vehicles (e.g., starting in 2017 each electric vehicle will count as two vehicles; see U.S. EPA 2012).
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 ICCT (2015) 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 who, all else being equal, serve customers with higher values of $\theta_H$ as “higher-end” OEMs.

In our model we have considered the market to be homogeneous with respect to how much customers value vehicle use $\nu$. However, markets with different locations or demographics may be characterized by different $\nu$ values. Therefore, if for certain OEMs, a strategy is optimal under a wider range of $\nu$ 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 $\theta_H$.

**Proposition 5.** $\partial \tilde{\nu} / \partial \theta_H > 0$ and $\partial (\bar{\nu} - \nu) / \partial \theta_H > 0$.

The first part of Proposition 5 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 $\theta_H$ increases the potential cannibalization. In such cases, to sell to both segments, the OEM has to significantly decrease the price it charges the High segment, and for that reason it induces $(O, \emptyset)$ 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 the 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 $(O, \emptyset)$
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 5 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 6.** When the CAFE standard is binding at optimality, \(\partial F^*_H(O, \emptyset) / \partial R < 0\), \(\partial F^*_H(O, O) / \partial R > 0\), and \(\partial F^*_L(O, O) / \partial R > 0\). Furthermore, \(\partial p^* / \partial R < 0\) whereas \(\partial F^*_H(O, M) / \partial R < 0\) if and only if \(a < \frac{\theta_H - g}{g - \theta_L}\).

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 \((O, \emptyset)\), the OEM indeed lowers the selling price due to the increase in the fuel efficiency of its vehicles. In contrast, under \((O, O)\), we find that the OEM increases both 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 customers of the Low segment 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
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$(O, M)$ and larger values of $a$, the OEM typically decreases the selling price to discourage the customers of the High segment 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 7. If the OEM is focused on sales only and the CAFE standard is binding at optimality, $\frac{\partial \tilde{v}}{\partial R} < 0$ for $R \in [r(O, O), e^*_L(O, O))$ and $\frac{\partial \tilde{v}}{\partial R} \geq 0$ for $R \geq e^*_L(O, O)$. With car sharing, if the CAFE standard is binding at optimality, $\frac{\partial (\bar{\nu} - \nu)}{\partial R} > 0$.

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 $(O, \emptyset)$ with $(O, O)$. In 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 $(O, \emptyset)$. This happens despite the fact that under $(O, O)$ the OEM increases its selling prices and sells vehicles of higher driving performance (i.e., lower efficiency) to the High segment than under $(O, \emptyset)$. The reason is that by selling only to 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 increasing popularity of car sharing as a viable alternative to car ownership and the growing involvement of OEMs in the car sharing business. Specifically, in this paper we identify the value that an OEM can derive from introducing car sharing and characterize the conditions under which this strategy holds the most economic and environmental potential. We determine the OEM’s optimal choice of business models and product line by balancing the trade-off between vehicle driving performance and fuel efficiency. Given the enactment of required CAFE standards and the fact that they are
scheduled to increase steeply in the near future, we also evaluate the effect of regulation on the OEM’s overall strategy and offer insights with respect to the different types of OEMs and markets found in practice.

When markets can be categorized based on the valuation customers assign to having access to a car (which can be a function of other market attributes such as available parking, public transportation options, etc.), our analysis reveals that OEMs prefer to introduce car sharing in markets where customers have moderate valuations of vehicle use. Such a middle ground implies that the OEM should not base its decision to introduce car sharing in a market entirely on the potential increase in market coverage, as it may actually benefit from having some existing customers switch from car ownership to car sharing even if the market is currently fully covered. Furthermore, although car sharing can deter customers from buying cars, it allows for better price discrimination and enables the OEM to charge higher prices for the vehicles it sells. Finally, we also find that higher-end OEMs benefit more from including car sharing in their business models. This is an important finding as it may help explain why higher-end OEMs such as Daimler and BMW have been introducing car sharing programs. Our is the first study to characterize the OEM’s benefits from offering car sharing.

Counter to some recent claims, we find that introducing car sharing does not always benefit the environment. Even in cases where car sharing is environmentally superior, the pooling effect of car sharing may actually decrease the OEM’s CAFE level. This finding has clear policy implications as it suggests that OEMs offering car sharing should be granted incentive multipliers for each shared vehicle they provide. Otherwise, OEMs may be disincentivized from adopting a car sharing business model despite it being both economically and environmentally superior. 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. This is the first study to identify and characterize the connection between the OEM’s incentive to offer car sharing and the existing environmental regulation in the automotive industry.

In order 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. Therefore, 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, as also evidenced by the fact that in Germany, Ford is currently providing car sharing through its dealerships (Ford 2015).

Finally, in our customer utility, the vehicle unavailability represented the main form of customer inconvenience. In practice, customers may experience additional forms of inconvenience when meeting their transportation needs through car sharing such as anxiety about potentially not finding a vehicle available when needed, the need to budget extra commute time in order 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 regarding the appeal of car sharing to customers.

Appendix
In what follows we provide details on the proofs of our results. The analytical expressions are explicitly given unless they hinder manuscript readability in which case only the shorthand notation is provided. For instance, instead of providing the complete expression of the optimal profit under the \((O, M)\) equilibrium we use \(\Pi^*_{(O, M)}\) to denote it. The complete forms are available from the authors upon request. When comparing across different equilibria we utilize the notation \((h, l)\) with \(h \in \{O\}\) and \(l \in \{O, M, \emptyset\}\). For instance, \(e^*_{H}(O, M)\) denotes the optimal fuel efficiency of the vehicles sold to the High segment under the \((O, M)\) equilibrium.

**Proof of Remark 1.** Assume that each customer requests a vehicle according to a Poisson process with rate \(\lambda'\) and that the mean duration of each vehicle use is \(\tau\). Set \(\lambda' \tau = d\),
where \( d \) denotes customers’ transportation needs. We model a network that comprises a single-server \( \bullet/M/1 \) node and an infinite-capacity \( \bullet/G/\infty \) node (Figure 2a). 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, which we model using a Poisson process with rate \( \lambda = n_i \lambda' \), where \( n_i \) is the size of the segment served through Membership. 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). Hence, the utilization \( \rho_{\bullet/M/1} \) provides the probability that a customer finds a vehicle available.

When a car leaves the \( \bullet/M/1 \) node, it serves a customer for the needed usage duration and then returns to the \( \bullet/M/1 \) node. We assume that customer usage times are independent and identically distributed according to a general probability distribution \( G(\cdot) \) with mean \( \tau \). Therefore, we capture the service process through the infinite capacity \( \bullet/G/\infty \) node whose service time distribution is \( G(\cdot) \).

Figure 2 Membership as a queuing network.

(a) Closed queueing network

(b) Open network for FPM approximation

The OEM guarantees an exogenously determined service level \( a \), by choosing \( S \) such that \( a = \rho_{\bullet/M/1} \). To calculate \( S \), we use the FPM approximation developed by Whitt (1984) based on which we construct the open counterpart of the closed queueing network and equate the expected equilibrium population of the open network to \( S \). Consider the open network shown in Figure 2b. The \( M/M/1 \) node is characterized by external Poisson arrivals with rate \( \lambda_c \) and exponential service times with parameter \( \lambda \). The service rate of each server at the \( M/G/\infty \) node is \( 1/\tau \) and the expected number of jobs (i.e., vehicles) in the open network is \( \mathbb{E}[N_c] = \mathbb{E}[N_{M/M/1}] + \mathbb{E}[N_{M/G/\infty}] = \frac{\lambda_c}{\lambda - \lambda_c} + \lambda_c \tau \). For the open network to be equivalent to the closed network, the external rate \( \lambda_c \) must satisfy \( \mathbb{E}[N_c] = S \). In this
case, $\rho_{M/M/1} = \frac{\lambda}{\lambda}$ determines the service level, which must equal $\lambda$. Substituting $\lambda_c = a\lambda$ in $\mathbb{E}[N_c] = S$ results in $S(a) \approx \frac{n_i}{1-a} + a\lambda\tau$. Given that $\lambda \leq n_i' \lambda'$ and $d \leq \lambda'\tau$, the fleet size that achieves an availability level $a$ is $S(a) \approx \frac{n_i}{1-a} + an_i'd. \square$

**Proof of Propositions 1 and 2.** For each possible equilibrium we first determine the optimal prices and then the optimal fuel efficiencies.

Under $(O,\emptyset)$ and for given efficiencies, the OEM determines the selling price $F$ based on $\max_F \Pi_{(O,\emptyset)} = (F - c_v(1 - e_H)^2 - c_e e_H^2)n_H$ subject to the individual rationality constraints $d(\nu + (1 - e_H)(\theta_H - g) - F \geq 0$ and $d(\nu + (1 - e_H)(g - \theta_L) - F \leq 0$ which can be rewritten as $d(\nu + (1 - e_H)(g - \theta_L) - F \leq d(\nu + (1 - e_H)(\theta_H - g))$. The profit $\Pi_{(O,\emptyset)}$ is linear increasing in $F$. Therefore, for a given fuel efficiency the optimal selling price is $\tilde{F} = d(\nu + (1 - e_H)(\theta_H - g))$. Define $\Pi_{(O,\emptyset)} = \Pi_{(O,\emptyset)}(F = \tilde{F})$. Then, the OEM determines the optimal fuel efficiency based on $\max_{e_H} \Pi_{(O,\emptyset)}$ such that $0 \leq e_H \leq 1$. $\Pi_{(O,\emptyset)}$ is concave in the fuel efficiency because $\frac{\partial^2 \Pi_{(O,\emptyset)}}{\partial^2 e_H} = -2(c_v + c_e)n_H < 0$, therefore, after solving $\frac{\partial^2 \Pi_{(O,\emptyset)}}{\partial e_H} = 0$ we obtain $e^*_H = \frac{d(\theta_H - g)}{2(c_v + c_e)}$. It is straightforward to show that $e^*_H \geq 0$ iff $c_v \geq \frac{d(\theta_H - g)}{2}$ and $e^*_H \leq 1$ iff $c_v \geq \frac{d(\theta_H - g)}{2}$, which is always true as $c_v < 0$. Following Chen (2001) we focus on interior values of $e^*_H \in (0,1)$. Hence, we assume that $c_v \geq \tilde{c}_v$. Based on $e^*_H$ we also calculate $F^* = d\nu + \frac{d(\theta_H - g)(2c_v + d(\theta_H - g) - 4c_ec_e)}{2(c_v + c_e)}$ and $\Pi^*(O,\emptyset) = n_H \left(d\nu + \frac{d(\theta_H - g)(4c_v + d(\theta_H - g)) - 4c_ec_e}{4(c_v + c_e)}\right)$.

Under $(O, O)$ and for given efficiencies, the OEM determines the selling prices $F_H$, and $F_L$ (we use the subscript $i = H$ and $i = L$ to indicate the selling price charged to the High and Low Segment, respectively) based on $\max_{F_H, F_L} \Pi_{(O, O)} = (F_H - c_v(1 - e_H)^2 - c_e e_H^2)n_H + (F_L - c_v(1 - e_L)^2 - c_e e_L^2)n_L$ subject to the individual rationality constraints $d(\nu + (1 - e_H)(\theta_H - g) - F_H \geq 0$ and $d(\nu + (1 - e_L)(\theta_L - g)) - F_L \geq 0$, and the incentive compatibility constraints $d(\nu + (1 - e_H)(\theta_H - g)) - F_H \geq d(\nu + (1 - e_L)(\theta_H - g)) - F_L$ and $d(\nu + (1 - e_L)(\theta_L - g)) - F_L \geq d(\nu + (1 - e_H)(\theta_L - g)) - F_H$. The individual rationality constraints can be rewritten as $F_H \leq d(\nu + (1 - e_H)(\theta_H - g))$ and $F_L \leq d(\nu + (1 - e_L)(\theta_L - g))$. Similarly, the incentive compatibility constraints are rewritten as $F_L + d(e_H - e_L)(g - \theta_L) \leq F_L \leq F_L + d(e_H - e_L)(\theta_H - g)$, which hold iff $e_L \geq e_H$ (we show below that at optimality $e_L > e_H$ holds). The profit $\Pi_{(O, O)}$ is linear increasing in both $F_H$ and $F_L$. Therefore, for given vehicle efficiencies, the optimal selling prices are $\tilde{F}_L = d(\nu + (1 - e_L)(\theta_L - g))$ and $\tilde{F}_H = \min \left\{\tilde{F}_L + d(e_L - e_H)(\theta_H - g), d(\nu + (1 - e_L)(\theta_H - g))\right\}$, from which is simple to show that $\tilde{F}_H = d(\nu + (1 - e_L)\theta_L + (e_L - e_H)\theta_H - (1 - e_H)g)$. 


Define $\tilde{\Pi}_{(O,O)} = \Pi_{(O,O)} \left(F_H = \tilde{F}_H, F_L = \tilde{F}_L\right)$. Then the OEM determines the optimal vehicle efficiencies based on $\max_{e_H,e_L} \tilde{\Pi}_{(O,O)}$ such that $0 \leq e_H \leq 1$ and $0 \leq e_L \leq 1$. The profit $\tilde{\Pi}_{(O,O)}$ is jointly concave in the vehicle efficiencies because $\partial^2 \tilde{\Pi}_{(O,O)}/\partial^2 e_H = -2(e_v + e_c) n_H < 0$, $\partial^2 \tilde{\Pi}_{(O,O)}/\partial^2 e_L = -2(e_v + e_c) n_H < 0$, and $\left(\partial^2 \tilde{\Pi}_{(O,O)}/\partial^2 e_H\right) \left(\partial^2 \tilde{\Pi}_{(O,O)}/\partial^2 e_L\right) - \left(\partial^2 \tilde{\Pi}_{(O,O)}/\partial e_H \partial e_L\right)^2 = 4(e_v + e_c)^2 n_H n_L > 0$. Therefore, after solving $\partial \tilde{\Pi}_{(O,O)}/\partial e_H = 0$ and $\partial \tilde{\Pi}_{(O,O)}/\partial e_L = 0$ we obtain $e_H^* = \frac{2c_v - d(\theta_H - g)}{2(c_v + c_e)n_L}$ and $e_L^* = \frac{2c_v n_L - d(g n_H + n_H \theta_H - (n_H + n_L) \theta_L)}{2(c_v + c_e)n_L}$. The efficiency $e_H^* \geq 0$ iff $c_v \geq \tilde{c}_v = \frac{d(\theta_H - g)}{2}$, and $e_H^* \leq 1$ iff $c_v \geq \bar{c}_v = \frac{d(n_H(\theta_H - \theta_L) + n_L(g - \theta_L))}{2n_L}$, which is always true as $\bar{c}_v < 0$. Similarly, $e_L^* \geq 0$ iff $c_v \geq \tilde{c}_v = \frac{d(n_H(g - \theta_L) + n_L(\theta_H - \theta_L))}{2n_L}$, which is always true as $\tilde{c}_v < 0$ and $e_L^* \leq 1$ iff $c_v \geq \bar{c}_v = \frac{d(n_H(\theta_H - \theta_L) + n_L(g - \theta_L))}{2n_L} > 0$. Once again, we focus on interior values $e_H^*, e_L^* \in (0,1)$ and for that reason we assume that $c_v > \tilde{c}_v$ and $c_e > \bar{c}_v$. It is straightforward to show that $e_L^* - e_H^* = \frac{d(n_H + n_L)(\theta_H - \theta_L)}{2(c_v + c_e)n_L} > 0$, which means that $e_L^* > e_H^*$ holds. Based on the optimal efficiencies, we also obtain $F_L^* = \frac{d(\theta_H - g)}{2(c_v + c_e)n_L}$, $F_H^* = F_L^* + \frac{d(n_H + n_L)(\theta_H - \theta_L)}{2(c_v + c_e)n_L}$, and $\Pi^*_{(O,O)} = (n_H + n_L) \left(d - \frac{4c_v c_e n_L - d(n_L(\theta_H - \theta_L))^2 + n_H(n_L(\theta_H - \theta_L)^2)}{4(c_v + c_e)n_L}\right)$.

Under $(O,M)$ for given efficiencies, the OEM determines the selling price $F$ and the per-unit-of-time price $p$ based on $\max_{F,p} \Pi_{(O,M)} = (F - c_v(1 - e_H)^2 - c_e e_H^2) n_H + a(p - g(1 - e_L)) n_L d - (c_v(1 - e_L)^2 + c_e e_L^2) \left(\frac{a}{1-a} + an_L d\right)$ subject to the individual rationality constraints $d(\nu + (\theta_H - g)(1 - e_H)) - F \geq 0$ and $ad(\nu + \theta_L(1 - e_L) - p) \geq 0$, and the incentive compatibility constraints $d(\nu + (\theta_H - g)(1 - e_H)) - F \geq ad(\nu + \theta_H(1 - e_L) - p)$ and $ad(\nu + \theta_L(1 - e_L) - p) \geq d(\nu + (\theta_L - g)(1 - e_L)) - F$. The individual rationality constraints can be rewritten as $F \leq d(\nu + (\theta_H - g)(1 - e_H))$ and $p \leq \nu + \theta_L(1 - e_L)$. Similarly, the incentive compatibility constraints are rewritten as $d(ap + (1-a)\nu - (1 - e_H)(g - \theta_L) - a(1 - e_L) \theta_L \leq F \leq d(ap + (1-a)\nu - (1 - e_H)(\theta_H - g) - a(1 - e_L) \theta_H$, which hold iff $e_L \geq e_H$ (we show below that at optimality $e_L > e_H$ holds). The profit $\Pi_{(O,M)}$ is linear increasing in both $F$ and $p$. Therefore, for given vehicle efficiencies the optimal per-unit-of-time price is $\tilde{p} = \nu + (1 - e_L) \theta_L$ and the optimal selling price is $\tilde{F} = d(a\tilde{p} + (1-a)\nu - (1 - e_H)(\theta_H - g) - a(1 - e_L) \theta_H$. Define $\Pi_{(O,M)} = \Pi_{(O,M)} \left(F = \tilde{F}, p = \tilde{p}\right)$. Then, the OEM determines the optimal vehicle efficiencies based on $\max_{e_H,e_L} \tilde{\Pi}_{(O,M)}$ such that $0 \leq e_H \leq 1$ and $0 \leq e_L \leq 1$. The profit $\tilde{\Pi}_{(O,M)}$ is jointly concave in the vehicle efficiencies because $\partial^2 \tilde{\Pi}_{(O,M)}/\partial^2 e_H = -2(e_v + e_c) n_H < 0$, $\partial^2 \tilde{\Pi}_{(O,M)}/\partial^2 e_L = -2(e_v + e_c) a \left(d n_L + \frac{1}{1-a}\right) < 0$, and
\[
\left( \frac{\partial^2 \tilde{\Pi}_{(O,M)}}{\partial^2 e_H} \right) \left( \frac{\partial^2 \tilde{\Pi}_{(O,M)}}{\partial^2 e_L} \right) - \left( \frac{\partial^2 \tilde{\Pi}_{(O,M)}}{\partial e_H \partial e_L} \right)^2 = \frac{4(c_v + c_e)^2 n_H a (1 - a) dn_L}{1 - a} > 0.
\]

Therefore, after solving \( \frac{\partial \tilde{\Pi}_{(O,M)}}{\partial e_H} = 0 \) and \( \frac{\partial \tilde{\Pi}_{(O,M)}}{\partial e_L} = 0 \) we obtain \( e_H^* = \frac{2c_v - (\theta_H - g)}{2(c_v + c_e)} \) and \( e_L^* = \frac{2c_e (1 - (a) dn_L) - d(1 - a) (g - \theta_L) n_L + (\theta_H - \theta_L) n_H}{2(c_v + c_e + (1 - (a) dn_L))} \). The efficiency \( e_H^* \geq 0 \) iff \( c_v \geq \bar{c}_v = \frac{d(\theta_H - g)}{2} > 0 \) and \( e_H^* \leq 1 \) iff \( c_v \geq \bar{c}_v = \frac{d(\theta_H - g)}{2} \), which is always true as \( \bar{c}_v < 0 \). With respect to \( e_L^* \), in this case we have that \( e_L^* \geq 0 \) iff \( c_v \geq \bar{c}_v = \frac{(1 - a)d(g - \theta_L)n_L + (\theta_H - \theta_L)n_H}{2(1 - (a) dn_L)} \), which is always true as \( \bar{c}_v < 0 \). In addition, \( e_L^* \geq 1 \) iff \( c_e \geq \bar{c}_e = \frac{(1 - a)d(g - \theta_L)n_L + (\theta_H - \theta_L)n_H}{2(1 - (a) dn_L)} > 0 \). As before, our focus is on interior values \( e_H^*, e_L^* \in (0, 1) \) and for that reason we assume that \( c_v > \bar{c}_v \) and \( c_e > \bar{c}_e \). Based on the optimal efficiencies we also obtain the optimal prices \( F^* \) and \( p^* \) along with the optimal profit \( \Pi^*_{(O,M)} \) (analytical expressions available upon request).

Note that the difference \( \hat{c}_e - \tilde{c}_e = \frac{d(-1 - (a)n_L + (1 - d)n_L)}{2n_L (1 - (a) dn_L)} > 0 \) due to \( n_L > \bar{n}_L \). This implies that \( e_i^* (h, l) \in (0, 1) \) for all \( i \in \{H, L\}, h \in \{O\} \), and \( l \in \{O, M\} \) when \( c_v > \bar{c}_v \) and \( c_e > \bar{c}_e \).

By comparing the fuel efficiencies under the different market equilibria we find that \( e_H^* (O, \emptyset) = e_H^* (O, O) = e_H^* (O, M) = \frac{2c_v - (\theta_H - g)}{2(c_v + c_e)} \) and \( e_L^* (O, O) - e_H^* (O, O) = \frac{d(n_H + n_L)(\theta_H - \theta_L)}{2(c_v + c_e)n_L} > 0 \), therefore, \( e_L^* (O, O) > e_H^* (O, O) \). Similarly, given that \( n_L > \bar{n}_L \), \( e_L^* (O, M) - e_H^* (O, O) = \frac{d(-1 - (a)n_L + (1 - d)n_L)}{2n_L (1 - (a) dn_L)} > 0 \), and \( e_L^* (O, O) - e_L^* (O, M) = \frac{d(-1 -(1-a)n_L - (1-d)n_L)}{2n_L (1 - (a) dn_L)} > 0 \), hence, \( e_L^* (O, M) > e_H^* (O, M) \) and \( e_L^* (O, M) > e_L^* (O, O) \).

In terms of comparative statics we obtain: \( \partial e_H^*/\partial \theta_H = -\frac{d}{2(c_v + c_e)} < 0, \partial e_L^*/\partial d = -\frac{\theta_H - g}{2(c_v + c_e)} < 0, \partial e_L^*/\partial n_L > 0, \partial e_L^*/\partial \theta_L = -\frac{dn_L(\theta_H - \theta_L)}{2(c_v + c_e)n_L^2} < 0, \partial e_L^*/\partial a > 0, \partial e_L^*/\partial \theta_H = \frac{d(-1 -(a)n_L - (1-d)n_L)}{2(c_v + c_e)(1 + dn_L(1-a))} > 0 \) and \( \partial e_L^*/\partial \theta_L = -\frac{dn_L(\theta_H - \theta_L)}{2(c_v + c_e)(1 + dn_L(1-a))^2} < 0 \), \( \partial e_L^*/\partial \theta_L = \frac{d(-1 -(a)n_L - (1-d)n_L)}{2(c_v + c_e)(1 + dn_L(1-a))} > 0 \), \( \partial e_L^*/\partial \theta_L = -\frac{dn_L(\theta_H - \theta_L)}{2(c_v + c_e)(1 + dn_L(1-a))^2} < 0 \), and \( \partial e_L^*/\partial \theta_L = \frac{d(-1 -(a)n_L - (1-d)n_L)}{2(c_v + c_e)(1 + dn_L(1-a))} > 0 \) if \( n_L < \frac{g - \theta_L}{d(1 - a)(\theta_H - \theta_L)} \).

Using a similar notation to distinguish between the prices under different equilibria we have, \( F_H^* (O, O) = F_L^* (O, O) = \frac{d(n_H + n_L)(\theta_H - g)(\theta_H - \theta_L)}{2(c_v + c_e)n_L} > 0, F_H^* (O, M) - F_H^* (O, O) = \frac{d(\theta_H - \theta_L)(2(1-a)c_n L (1 + (1-a)dn_L) + d(1-a)n_L(a - d - 1)(\theta_H - \theta_L)n_H + (\theta_L)n_H)}{2n_L(c_v + c_e)(1 - (a) dn_L)} > 0 \) due to \( c_e > \bar{c}_e \) and \( n_L > \bar{n}_L \), and \( F_H^* (O, \emptyset) - F_H^* (O, M) = \).

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6 As we have already stated in §4.2 of the main paper, throughout the analysis we assume that \( n_L > \bar{n}_L \), otherwise \((O, M)\) is always dominated (the derivation of the condition is provided in the proof of Proposition 4).
\[ \frac{d\alpha(\theta_H-\theta_L)}{2c_0\left(1+(1-a)dn_L\right)} - \frac{d(1-a)}{2(c_0+c_0)(1+(1-a)dn_L)} \left( (\theta_H-\theta_L)n_H + (g-\theta_L)n_L \right) > 0 \] due to \( c_e > \hat{c}_e \). Therefore, \( F_H^*(O,\emptyset) > F_H^*(O,M) > F_H^*(O,O) > F_L^*(O,O) \).

**Proof of Proposition 3.** We start by calculating the CAFE level under the different equilibria. Specifically, \( r(O,\emptyset) = \epsilon_H^* = \frac{2c_e-d(\theta_H-g)}{2(c_0+c_0)} \), \( r(O,M) = \frac{n_H}{n_H+n_L} \epsilon_H^* + \frac{n_L}{n_H+n_L} \epsilon_L^* = \frac{2c_e-d(\theta_L)}{2(c_0+c_0)} \), and \( r(O,M) = \frac{n_H}{n_H+n_L} \epsilon_H^* + \frac{n_L}{n_H+n_L} \epsilon_L^* \). We continue by calculating the difference \( r(O,O) - r(O,\emptyset) = \frac{d(\theta_H-\theta_L)}{2(c_0+c_0)(a+(1-a)(dn_L+n_H))} > 0 \), which implies that \( r(O,O) > r(O,\emptyset) \). With respect to the CAFE under \( (O,O) \) and \( (O,M) \) we have \( r(O,O) - r(O,M) = \frac{d(\theta_H-\theta_L)}{2(c_0+c_0)(a+(1-a)(dn_L+n_H))} \), which can be positive or negative. However, \( \frac{\partial r(O,O) - r(O,M)}{\partial \theta_H} = \frac{dH}{2(c_0+c_0)(a+(1-a)(\alpha_H+\alpha_L))} > 0 \), therefore, \( r(O,O) > r(O,M) \) for all \( \theta_H > \bar{\theta}_H = \{ \theta_H : r(O,O) - r(O,M) = 0 \} \) and \( \theta_H > \bar{\theta}_L \) because \( \bar{\theta}_H - \bar{\theta}_L = \frac{a(\theta-H)(1+(1-a)\alpha_H+\alpha_L)}{\alpha_H^*} > 0 \) for all \( \nu > \nu^* \).

**Proof of Proposition 4.** We observe that the OEM’s profit always increases in \( \nu \) as \( \frac{\partial \Pi^*_\emptyset}{\partial \nu} = d\alpha_H > 0 \), \( \frac{\partial \Pi^*_\emptyset \emptyset}{\partial \nu} = d(n_H + n_L) > 0 \) and \( \frac{\partial \Pi^*_{\emptyset M}}{\partial \nu} \) with \( \frac{\partial \Pi^*_\emptyset \emptyset}{\partial \nu} \) greater than \( \frac{\partial \Pi^*_{\emptyset O}}{\partial \nu} \). Define \( \nu \equiv \{ \nu : \Pi^*_{\emptyset O} - \Pi^*_{\emptyset \emptyset} = 0 \} \) and \( \nu \equiv \{ \nu : \Pi^*_{\emptyset M} - \Pi^*_{\emptyset \emptyset} = 0 \} \) (analytical expressions available upon request). We also calculate \( \frac{d(\Pi^*_{\emptyset M} - \Pi^*_{\emptyset \emptyset})}{d\nu} = d(\alpha_H > 0 \) and \( \frac{d(\Pi^*_{\emptyset M} - \Pi^*_{\emptyset \emptyset})}{d\nu} = d(n_H > 0 \) therefore, with car sharing, the OEM prefers to induce \( (O,M) \) over \( (O,\emptyset) \) for all \( \nu \geq \nu^* \) and \( (O,M) \) over \( (O,O) \) for all \( \nu < \nu^* \). For \( (O,M) \) to exist it is necessary that \( \nu - \nu^* = \frac{a(\theta_H-\theta_L)}{2(c_0+c_0)(1+(1-a)\alpha_H+\alpha_L)} > 0 \) and \( \nu - \nu^* = \frac{a(\theta_H-\theta_L)}{2(c_0+c_0)(1+(1-a)\alpha_H+\alpha_L)} > 0 \), both of which are true if \( n_L > n_H > \frac{1}{\alpha_H} \). When \( n_L > \frac{n_H}{\alpha_H} \), the thresholds \( \nu \) fast and \( \nu \) are guaranteed to exist as \( \nu \geq \nu^* \). Hence, the OEM induces i) \( (0,\emptyset) \) for all \( \nu \geq [0,\nu^+] \), ii) \( (0,\emptyset) \) for all \( \nu \in [\nu^-,\nu^+] \), iii) \( (O,M) \) for all \( \nu \in [\nu^-,\nu^+] \) and iv) \( (O,O) \) for all \( \nu > \nu^* \).
Proof of Corollary 1. For all \( \nu \in [\tilde{\nu}, \tilde{\nu}] \) the OEM replaces \((O, \emptyset)\) with \((O, M)\). We have \( E(O, \emptyset) = \zeta_p n_H + \zeta_u (e_H^*) d n_H \) and \( E(O, M) = \zeta_p (n_H + \frac{a}{1-a} + a n_L d) + \zeta_u (e_H^*) d n_H + \zeta_u (e_L^*) a d n_L \), where \( \zeta_u (e_L^*) < \zeta_u (e_H^*) \) because \( e_L^* > e_H^* \). The change in the impact is given by \( E(O, M) - E(O, \emptyset) = a \left( \frac{1}{1-a} \zeta_p + d (\zeta_p + \zeta_u (e_L^*) n_L) \right) > 0 \), therefore, \( E(O, M) > E(O, \emptyset) \). For all \( \nu \in [\tilde{\nu}, \tilde{\nu}] \) the OEM replaces \((O, O)\) with \((O, M)\). We have \( E(O, O) = \zeta_p (n_H + n_L) + \left( \zeta_u (e_H^*) n_H + \zeta_u (e_L^* (O, O)) n_L \right) d \) and \( E(O, M) = \zeta_p (n_H + \frac{a}{1-a} + a n_L d) + \zeta_u (e_H^*) d n_H + \zeta_u (e_L^* (O, M)) a d n_L \), where \( \zeta_u (e_L^* (O, M)) < \zeta_u (e_L^* (O, O)) < \zeta_u (e_H^*) \) because \( e_L^* (O, M) > e_L^* (O, O) > e_H^* \). The change in the impact is given by \( E(O, M) - E(O, O) = \zeta_p \left( \frac{n}{1-a} - (1 - a d) n_L \right) + \left( a \zeta_u (e_L^* (O, M)) - \zeta_u (e_L^* (O, O)) \right) n_L < 0 \) for all \( n_L > \bar{n}_L \), hence, \( E(O, M) < E(O, O) \).

The fact that \( r(O, M) < r(O, O) \) when \( \theta_H > \bar{\theta}_H \) was shown in Proposition 3. If the average fleet efficiency is based on the number of customers served \( r'(O, M) = \frac{n_H}{n_H + n_L} e_H^* + \frac{n_L}{n_H + n_L} e_L^* = n_H \left( \frac{2c_e - d (\theta_H - g)}{2(c_e + c_e)(n_H + n_L)} \right) + n_L \left( \frac{2c_e - d (\theta_H - g)}{2(c_e + c_e)(n_H + n_L)} \right) \), given that \( n_L > \bar{n}_L \), \( r'(O, M) - r(O, O) = \frac{d}{2(c_e + c_e)n_L} \left( -1 + (1-a)(1-n_L) \right) (g - \theta_{e_L}) n_L + (g - \theta_{e_L}) n_H > 0 \) for all \( \theta_H \). □

Proof of Proposition 5. The range of \( \nu \) values for which the OEM prefers to induce \((O, O)\) over \((O, \emptyset)\) increases in \( \theta_H \) because \( \partial \bar{\nu} / \partial \theta_H = \frac{n_H}{2(c_e + c_e)n_L^2} \left( -1 + (1-a)(1-n_L) \right) (g - \theta_{e_L}) n_L + (g - \theta_{e_L}) n_H > 0 \) for all \( n_L > \bar{n}_L \). □

Proof of Proposition 6. It follows the proof of Propositions 1 and 2 with the difference that when optimizing \( \tilde{\Pi}_{[h,l]} \) the CAFE constraint \( r(h, l) > R \) is binding (i.e., the regulation \( R \) exceeds the CAFE levels calculated in Proposition 3). As before, we focus on interior values of fuel efficiencies.

Under \((O, \emptyset)\) the OEM determines the optimal efficiency based on \( \max_{0 \leq s_H \leq 1} \tilde{\Pi}_{(O, \emptyset)} \). The profit \( \tilde{\Pi}_{(O, \emptyset)} \) is concave in \( e_H \), therefore, if \( R \) is larger than the unconstrained optimal efficiency calculated in Proposition 1, the OEM chooses \( e_H^* = R \), which results in \( F_H^* = d \left( \theta_H - g \right) (1 - R) + \nu \) and \( \partial F_H^*/\partial R = -d (\theta_H - g) < 0 \).

Under \((O, O)\) the OEM determines the optimal efficiencies based on \( \max_{e_H, e_L} \tilde{\Pi}_{(O, O)} \) such that \( 0 \leq e_H \leq 1, 0 \leq e_L \leq 1 \) and \( \frac{n_H}{n_H + n_L} e_H + \frac{n_L}{n_H + n_L} e_L \geq R \). We form the Lagrangean \( L = \tilde{\Pi}_{(O, O)} + \psi \left( \frac{n_H}{n_H + n_L} e_H + \frac{n_L}{n_H + n_L} e_L - R \right) \). Given that \( \tilde{\Pi}_{(O, O)} \) is jointly concave in \( e_H \) and \( e_L \) we solve \( \partial L / \partial e_H = 0 \), \( \partial L / \partial e_L = 0 \) and \( \partial L / \partial \psi = 0 \) to obtain \( e_H^* = R - \frac{d (\theta_H - \theta_{e_L})}{2(c_e + c_e)} \), \( e_L^* = R + \frac{d (\theta_H - \theta_{e_L})}{2(c_e + c_e)n_L} \), and \( \psi = (n_H + n_L) (2(c_e + c_e) R -
Paralleling Proposition 4, we calculate \( \tilde{\nu} \).

Similarly, for \( \theta \) we develop in the Proof of Propositions 1 and 2 for the 

Under \( (O, M) \) the OEM determines the optimal efficiencies based on max \( e_H, e_L, \tilde{\Pi}_{(O,M)} \)

The analytical expressions for \( F_H \) and \( p^* \) are available upon request. By differentiating we obtain \( \partial \theta_L < 0 \), and \( \partial F_H^* (O, M) / \partial R = d (g - (1 - a) \theta_L - a \theta_L) < 0 \) if \( a < \frac{\theta_H - g}{\theta_H - \theta_L} \). \( \square \)

**Proof of Proposition 7.** For brevity define \( \tilde{\Pi}^*_0, \tilde{\Pi}^*_O, \) and \( \tilde{\Pi}^*_{(O,M)} \) to be the unconstrained optimal profits we developed in the Proof of Propositions 1 and 2 for the \( (O, \emptyset), (O, O), \) and \( (O, M) \) equilibrium, respectively. Using the optimal prices and fuel efficiencies we calculated in Proposition 6 we obtain the constrained optimal profits \( \Pi^*_{(O,M)} = \tilde{\Pi}^*_{(O,M)} - \frac{n_H}{4(c_c + c_e)} \left( 2c_c - 2(c_c + c_e) R - d(g - \theta_L) \right)^2 - \left( 1 - a \right) R (1 - a) n_H + n_H + 1 + g (1 - a) n_H + 1 - (1 - a) \theta_L (n_H + n_L) \)

Paralleling Proposition 4, we calculate \( \tilde{\nu} = \left\{ \nu : \tilde{\Pi}^*_{(O,M)} - \tilde{\Pi}^*_O = 0 \right\} \), \( \nu = \left\{ \nu : \Pi^*_{(O,M)} - \Pi^*_O = 0 \right\} \) and \( \tilde{\nu} = \left\{ \nu : \Pi^*_{(O,M)} - \Pi^*_O = 0 \right\} \). When selling only \( r(O, \emptyset) > r(O, \emptyset) \) (see Proposition 3), hence, the CAFE standard is binding for either equilibrium when \( R \geq r(O, \emptyset) \). \( \tilde{\nu} \) is convex in \( R \) because \( \partial^2 \tilde{\nu} / \partial R^2 = \frac{2(c_c + c_e)}{d} > 0 \). In addition, \( \partial \tilde{\nu} / \partial R |_{R = e_L^*(O, O)} = 0 \). Therefore, \( \partial \tilde{\nu} / \partial R > 0 \) for all \( R \geq e_L^*(O, O) \) and \( \partial \tilde{\nu} / \partial R < 0 \) for all \( R \in [r(O, M), e_L^*(O, O)] \). With car sharing \( r(O, M) > r(O, \emptyset) \) for \( \theta_L > \tilde{\theta}_L \) and \( r(O, M) > r(O, \emptyset) \) for \( \theta_L < \tilde{\theta}_L \) (see Proposition 3). Hence, for \( \theta_L > \tilde{\theta}_L \) the CAFE standard is binding when \( R \geq r(O, O) \). The range \( \tilde{\nu} - \nu \) is convex in \( R \) because \( \partial^2 (\tilde{\nu} - \nu) / \partial R^2 = \frac{2(c_c + c_e)(1 - (1 - d) n_H (1 - a))}{4 n_H (1 - a)^2} > 0 \) for \( n_L > n_L \). Furthermore, \( \partial (\tilde{\nu} - \nu) / \partial R |_{r(O, O)} = \frac{d(g - \theta_L) (1 - (1 - d) n_L (1 - a))}{2(1 - a)^2 d n_L} > 0 \) for \( n_L > n_L \). Therefore, \( \partial (\tilde{\nu} - \nu) / \partial R > 0 \) for all \( R > r(O, O) \). Similarly, for \( \theta_L < \tilde{\theta}_L \) the CAFE standard is binding when for \( R \geq r(O, M) \). In this
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\[ \frac{\partial (\bar{\nu} - \nu)}{\partial R} \bigg|_{R = r(O,M)} = \frac{\left(\frac{-1 + (1 - a)n_L(1-d)}{(1-a)n_L(1-a)(adn_L + n_H) + a}\right)}{n_H\left(a(\theta_H - \theta_L) - (\theta_H - g)\right) + an_L(g - \theta_L)} > 0 \]  

for \( n_L > n_H \) and \( \theta_H < \bar{\theta}_H \). Therefore, \( \frac{\partial^2 (\bar{\nu} - \nu)}{\partial^2 R} = \frac{2(c + c_e)(-1 + (1 - d)n_L(1-a))}{dn_L(1-a)^2} > 0 \) implies that \( \frac{\partial (\bar{\nu} - \nu)}{\partial R} > 0 \) for all \( R > r(O,M) \). Thus, \( \frac{\partial (\bar{\nu} - \nu)}{\partial R} > 0 \) for all \( \theta_H \).

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