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Peer-to-Peer Product Sharing: Implications for Ownership, Usage, and Social Welfare in the Sharing Economy

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Abstract. We describe an equilibrium model of peer-to-peer product sharing, or collaborative consumption, where individuals with varying usage levels make decisions about whether or not to own a homogeneous product. Owners are able to generate income from renting their products to nonowners while nonowners are able to access these products through renting on an as-needed basis. We characterize equilibrium outcomes, including ownership and usage levels, consumer surplus, and social welfare. We compare each outcome in systems with and without collaborative consumption and examine the impact of various problem parameters. Our findings indicate that collaborative consumption can result in either lower or higher ownership and usage levels, with higher ownership and usage levels more likely when the cost of ownership is high. Our findings also indicate that consumers always benefit from collaborative consumption, with individuals who, in the absence of collaborative consumption, are indifferent between owning and not owning benefitting the most. We study both profit-maximizing and social-welfare–maximizing platforms and compare equilibrium outcomes under both in terms of ownership, usage, and social welfare. We find that the difference in social welfare between the profit-maximizing and social-welfare–maximizing platforms is relatively modest.

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1. Introduction

We are witnessing, across a wide range of domains, a shift away from the exclusive ownership and consumption of resources to one of shared use and consumption. This shift is taking advantage of innovative new ways of peer-to-peer sharing that are voluntary and enabled by Internet-based exchange markets and mediation platforms. Value is derived from the fact that many resources are acquired to satisfy infrequent demand but are otherwise poorly utilized (for example, the average car in the United States is used less than 5% of the time). Several successful businesses in the United States and elsewhere—such as Getaround for cars, Spinlister for bikes, 3D Hubs for 3D printers, LiquidSpace for office space, MachineryLink for farm equipment, and JustPark for parking—provide a proof of concept and evidence for the viability of peer-to-peer product sharing or collaborative consumption (the term we use in the rest of the paper). These businesses and others allow owners to rent poorly utilized assets on a short-term basis and nonowners to access these assets through renting on an as-needed basis. Collectively, these businesses and other manifestations of the collaborative consumption of products and services are giving rise to what is becoming known as the sharing economy.[1]

The peer-to-peer sharing of products is not a new concept. However, recent technological advances in several areas have made it more feasible by lowering the associated search and transaction costs. These advances include the development of online marketplaces, mobile devices and platforms, electronic payments, and two-way reputation systems whereby users rate providers and providers rate users. Other drivers behind the rise of collaborative consumption are societal and include increased population density in urban areas around the world, increased concern about the environment (collaborative consumption is viewed as a more sustainable alternative to traditional modes of consumption), and increased desire for community and altruism among the young and educated.

Collaborative consumption has the potential of increasing access while reducing investments in resources and infrastructure. In turn, this could have the twin benefit of improving consumer welfare (individuals who may not otherwise afford a product now have an opportunity to use it) while reducing societal costs (externalities, such as pollution that may be associated with the production, distribution, use, and disposal of the product). It also has the potential of providing a source of net income for owners by monetizing poorly utilized assets, which are in some cases also expensive and rapidly depreciating. Take cars, for example. The availability of a sharing option could lead some to forego car ownership in favor of on-demand access. In turn, this could result in a corresponding reduction in congestion and emissions, and, eventually, in reduced investments in roads and parking infrastructure. However, increased collaborative consumption may have other consequences, some of which may be undesirable. For example, greater access to cars could increase car usage and, therefore, lead to more congestion and pollution if it is not accompanied by a sufficient reduction in the numbers of cars.[2] It could also lead to speculative investments in cars and price inflation, or affect the availability and pricing of other modes of public transport, such as taxis, buses, and trains.

Collaborative consumption raises several important questions. How does collaborative consumption affect ownership and usage of resources? Is it necessarily the case that collaborative consumption leads to lower ownership, lower usage, or both (and therefore to improved environmental impact)? If not, what conditions would favor lower ownership, lower usage, or both? Who benefits the most from collaborative consumption among owners and renters? To what extent would a profit-maximizing platform, through its choice of rental prices, improve social welfare? To what extent do frictions, such as extra wear and tear renters place on rented resources and inconvenience experienced by renters, affect platform profit and social welfare?

In this paper, we address these and other related questions. We describe an equilibrium model of peer-to-peer product sharing, where individuals with varying usage levels make decisions about whether or not to own a homogeneous product. In the presence of collaborative consumption, owners are able to generate income from renting their products to nonowners while nonowners are able to access these products through renting. The matching of owners and renters is facilitated by a platform, which sets the rental price and charges a commission fee.[3] Because supply and demand can fluctuate over the short run, we allow for the possibility that an owner may not always be able to find a renter when she puts her product up for rent. Similarly, we allow for the possibility that a renter may not always be able to find a product to rent when he needs one. We refer to the uncertainty regarding the availability of renters and products as "matching friction" and describe a model for this uncertainty. We also account for the cost incurred by owners due to the extra wear and tear that a renter places on a rented product and for the inconvenience cost experienced by renters for using a product that is not their own.

For a given price and a commission rate, we characterize equilibrium ownership and usage levels, consumer surplus, and social welfare. We compare each in systems with and without collaborative consumption and examine the impact of various problem parameters including price, commission rate, cost of ownership, extra wear and tear cost, and inconvenience cost. We also do so when the price is a decision made by the platform to maximize either profit or social welfare. Our main findings include the following:

- Depending on the rental price, we show that collaborative consumption can result in either higher or lower ownership. In particular, we show that when the rental price is sufficiently high (above a well-specified threshold), collaborative consumption leads to higher ownership. We show that this threshold is decreasing in the cost of ownership. That is, collaborative consumption is more likely to lead to more ownership when the cost of ownership is high (this is because collaborative consumption allows individuals to offset the high ownership cost and pulls in a segment of the population that may not otherwise choose to own).
- Similarly, we show that collaborative consumption can lead to either higher or lower usage, with usage being higher when price is sufficiently high. Thus, it is possible for collaborative consumption to result in both higher ownership and higher usage (it is also possible for ownership to be lower but usage to be higher and for both ownership and usage to be lower).
- These results continue to hold in settings where the rental price is determined by a profit-maximizing or a social-welfare–maximizing platform. In particular, collaborative consumption can still lead to either higher or lower ownership and usage with higher ownership and usage more likely when the cost of ownership is higher.
- We show that consumers always benefit from collaborative consumption, with individuals who, in the absence of collaborative consumption, are indifferent between owning and not owning benefitting the most. This is because among nonowners, those with the most usage (and therefore end up renting the most) benefit the most from collaborative consumption. Similarly, among owners, those with the least usage (and therefore end up earning the most rental income) benefit the most.
- For a profit-maximizing platform, we show that profit is not monotonic in the cost of ownership, implying that a platform is least profitable when the cost of ownership is either very high or very low (those two extremes lead to scenarios with either mostly renters and few owners or mostly owners and few renters). The platform is most profitable when owners and renters are sufficiently balanced. For similar reasons, social

welfare is also highest when owners and renters are sufficiently balanced.

- We observe that profit is also not monotonic in the extra wear and tear renters place on a rented product, implying that a platform may not always have an incentive to reduce this cost. This is because the platform can leverage this cost to induce desirable ownership levels without resorting to extreme pricing, which can be detrimental to its revenue.
- We examine the robustness of our results by considering settings, among others, where (1) nonowners have the option of renting from a third-party service provider, (2) platforms may own assets of their own, (3) individuals are heterogeneous in their aversion to renting to/from others (i.e., their sensitivity to the costs of extra wear and tear and inconvenience), (4) usage is endogenous, and (5) usage has a general distribution.

The rest of the paper is organized as follows. In Section 2, we provide a review of related literature. In Section 3, we describe our model. In Section 4, we provide an analysis of the equilibrium. In Section 5, we consider the platform's problem. In Section 6, we discuss extensions. In Section 7, we offer concluding comments.

2. Literature Review

Our work is related to the literature on peer-to-peer markets (see Einav et al. 2016 for a recent review). Within this literature, there is a small but growing stream that deals with peer-to-peer markets with collaborative consumption features. Fradkin et al. (2015) studies sources of inefficiency in matching buyers and suppliers in online marketplaces. Using a counterfactual study, they show how changes to the ranking algorithm of Airbnb can improve the rate at which buyers are successfully matched with suppliers. Zervas et al. (2015) examine the relationship between Airbnb supply and hotel room revenue and find that an increase in Airbnb supply has only a modest negative impact on hotel revenue. Cullen and Farronato (2014) describe a model of peer-to-peer labor marketplaces. They calibrate the model using data from TaskRabbit and find that supply is highly elastic, with increases in demand matched by increases in supply per worker with little or no impact on price.

Papers that are closest in spirit to ours are Fraiberger and Sundararajan (2015) and Jiang and Tian (2018). Fraiberger and Sundararajan (2015) describe a dynamic programing model where individuals make decisions in each period regarding whether to purchase a new car, purchase a used a car, or not purchase anything. They model matching friction, as we do, but assume that the renter–owner matching probabilities are exogenously specified and not affected by the ratio of owners to renters (in our case, we allow for these to depend on the ratio of owners to renters that turns out to be critical in the decisions of individuals on whether to own or rent). They use the model to carry out a numerical study. For the parameter values they consider, they show that collaborative consumption leads to a reduction in new and used car ownership, an increase in the fraction of the population who do not own, and an increase in the usage intensity per vehicle. In this paper, we show that ownership and usage can actually either increase or decrease with collaborative consumption and provide analytical results regarding conditions under which different combinations of outcomes can occur. We also study the decision of the platform regarding pricing and the impact of various parameters on platform profitability.

Jiang and Tian (2018) describe a two-period model, where individuals first decide on whether or not to own a product. This is followed by owners deciding in each period on whether to use the product themselves or rent it. They assume that demand always matches supply through a market-clearing price and do not consider, as we do, the possibility of a mismatch, because of matching friction, between supply and demand. They focus on the decision of the product manufacturer. In particular, they study how the manufacturer should choose its retail price and product quality in anticipation of sharing by consumers. In contrast, we focus on the decision of the platform, which in our case decides on the rental price.

Empirical studies that examine the impact of peer-to-peer product sharing on ownership and usage are scarce. Clark et al. (2014) present results from a survey of British users of a peer-to-peer car-sharing service. They find that peer-to-peer car sharing has led to a net increase in the number of miles driven by car renters. Linden and Franciscus (2016) examine differences in the prevalence of peer-to-peer car sharing among several European cities. He finds that peer-to-peer car sharing is more prevalent in cities where a larger share of trips is taken by public transport and where there is a city center less suitable for car use. Ballus-Armet et al. (2014) report on a survey in San Francisco of public perception of peer-to-peer car sharing. They find that approximately 25% of surveyed car owners would be willing to share their personal vehicles through peer-to-peer car sharing, with liability and trust concerns being the primary deterrents. They also find that those who drive almost every day are less likely to rent through peer-to-peer car sharing, while those who use public transit at least once per week are more likely to do so. There are a few studies that consider car sharing that involves a third-party service provider, such as a car rental company. For example, Nijland et al. (2015) (and also Martin and Shaheen 2011) find that car sharing would lead to a net decrease in car usage. On the other hand, a study by KPMG (Korosec 2015) projects a significant increase in miles driven by cars and attributes this to increased usage of on-demand transportation services. In general, there does not appear to be a consensus yet on the impact of car sharing on car usage and ownership. Our paper, by providing a framework for understanding how various factors may affect product-sharing outcomes, could be useful in informing future empirical studies.

There is a growing body of literature that focuses on the concept of *servicization*. Servicization refers to a business model under which a firm that supplies a product to the market retains ownership of the product and instead charges customers per use (e.g., printer manufacturers charging customers per printed page instead of charging them for the purchase of a printer or car manufacturers renting cars on a short-term basis instead of selling them or leasing them on a long-term basis). Agrawal and Bellos (2017) examine the extent to which servicization affects ownership and usage, and the associated environmental impact.[4] Orsdemir et al. (2017) evaluate both the profitability and the environmental impact of servicization. Bellos et al. (2017) study the economic and environmental implications of an auto manufacturer, in addition to selling cars, offering a car-sharing service. Additional discussion and examples of servicization can be found in Agrawal and Bellos (2017) and the references therein. Peer-to-peer product sharing is different from servicization in that there is no single entity that owns the rental units, with owners being simultaneously consumers and suppliers of the market. As a result, the payoff of one side of the market depends on the availability of the other side. This, coupled with the fact that supply and demand are not guaranteed to be matched with each other, makes ownership and usage decisions more complicated than those under servicization.

Finally, we note that collaborative consumption has the features of a two-sided market (see, for example, Rochet and Tirole 2006, Weyl 2010, and Hagiu and Wright 2015). Collaborative consumption is different from two-sided markets in several ways, the most important of which is that the two sides are not distinct. In collaborative consumption, being either an owner or a renter is a decision that users of the platform make, with more owners implying fewer renters, and vice versa. Collaborative consumption also shares features of secondary markets for used goods (see, for example, Waldman 2003). Markets with collaborative consumption are different from those with a secondary market for used goods in that there is no permanent transfer of ownership from the seller to the buyer and the usage by the renter does not preclude usage by the owner.

3. Model Description

In this section, we describe our model of collaborative consumption. The model is applicable to the case of peer-to-peer product sharing where owners make their products available for rent when they are not using them and nonowners can rent from owners to fulfill their usage needs. We reference the case of car sharing. However, the model applies more broadly to the collaborative consumption of other products. We consider a population of individuals who are heterogeneous in their product usage, with their type characterized by their usage level ξ.[5] We assume that usage is exogenously determined (i.e., the usage of each individual is mostly inflexible). In Section 6, we consider the case where usage is endogenously determined and affected by the presence of collaborative consumption. We assume that the utility derived by an individual with type ξ, $u(\xi)$ is linear in ξ with $u(\xi) = \xi$. We use a linear utility for ease of exposition and to allow for closed-form expressions. A linear utility has constant returns to scale, and, without loss of generality, the utility derived from each unit of usage can be normalized to 1. Also without loss of generality, we normalize the usage level to $[0, 1]$, where $\xi = 0$ corresponds to no usage at all and $\xi = 1$ to full usage. We let $f(\xi)$ denote the density function of the usage distribution in the population. In Online Appendix A, we provide a summary of notation used throughout the paper.

We assume that products are homogeneous in their features, quality, and cost of ownership. In the absence of collaborative consumption, each individual makes a decision about whether or not to own. In the presence of collaborative consumption, each individual decides on whether to own, rent from others who own, or neither. Owners incur the fixed cost of ownership but can now generate income by renting their products to others who choose not to own. Renters pay the rental fee but avoid the fixed cost of ownership.

We let p denote the rental price per unit of usage that renters pay (a uniform price is consistent with observed practices by certain peer-to-peer platforms when the goods are homogeneous). This rental price may be set by a third party platform (an entity that may be motivated by profit, social welfare, or some other concern; see Section 5 for further discussion). The platform extracts a commission from successful transactions. We denote the commission rate as γ, where $0 \le \gamma < 1$, so that the rental income seen by the owner per unit of usage is $(1 - \gamma)p$. We let α, where $0 \le \alpha \le 1$ denote the fraction of time in equilibrium that an owner, whenever she puts her product up for rent, is successful in finding a renter. Similarly, we denote by β, where $0 \le \beta \le 1$, fraction of time that a renter, whenever he decides to rent, is successful in finding an available product (the parameters α and β are determined endogenously in equilibrium). A renter resorts to his outside option (e.g., public transport in the case of cars) whenever he is not successful in finding a product to rent. The owner incurs a fixed cost of ownership, denoted by c, which may include not just the purchase cost (if costs are expressed per unit time, this cost would be amortized accordingly) but also other ownership-related costs such as those related to storage and insurance. Whenever the product is rented, the owner incurs an additional cost, denoted by d_o, due to extra wear and tear the renter places on the product. Renters, on the other hand, incur an inconvenience cost, denoted by d_r (in addition to paying the rental fee), from using someone else's product and not their own. Without loss of generality, we assume that $c, p, d_o, d_r \in [0,1]$ and normalize the value of the outside option (e.g., using public transport) to 0.

We assume that $p(1-\gamma) \geq d_o$ so that an owner would always put her product out for rent when she is not using it. Note that usage corresponds to the portion of time an owner would like to have access to her product, regardless of whether or not she is actually using it. An owner has always priority in accessing her product. Hence her usage can always be fulfilled. We also assume that $p + d_r \leq 1$ so that a renter always prefers renting to the outside option. Otherwise, rentals would never take place as the outside option is assumed to be always available. There are of course settings where an individual would like to use a mix of options (e.g., different transportation methods). In that case, ξ corresponds to the portion of usage that an individual prefers to fulfill using the product (e.g., a car and not public transport).

The *payoff* of an owner with usage level ξ can now be expressed as

$$\pi_o(\xi) = \xi + (1-\xi)\alpha[(1-\gamma)p - d_o] - c, \tag{1}$$

while the payoff of a renter as

$$\pi_r(\xi) = \beta\xi - \beta(p + d_r)\xi. \tag{2}$$

The payoff of an owner has three terms: the utility derived from usage, the income derived from renting (net of the wear and tear cost), and the cost of ownership. The income from renting is realized only when the owner is able to find a renter. The payoff of a renter is the difference between the utility derived from renting and the cost of renting (the sum of rental price and inconvenience cost). A renter derives utility and incurs costs whenever he is successful in renting a product.[6]

An individual with type ξ would participate in collaborative consumption as an *owner* if the following conditions are satisfied

$$\pi_o(\xi) \geq \pi_r(\xi) \quad \text{and} \quad \pi_o(\xi) \geq 0.$$

The first constraint ensures that an individual who chooses to be an owner prefers to be an owner to being a renter. The second constraint is a participation constraint that ensures the individual participates in collaborative consumption. Similarly, an individual with type ξ would participate in collaborative consumption as a *renter* if the following conditions are satisfied

$$\pi_r(\xi) \geq \pi_o(\xi) \quad \text{and} \quad \pi_r(\xi) \geq 0.$$

Noting that, for any given pair of α and β in $[0,1]$, $\pi_o(\xi) - \pi_r(\xi)$ is monotonically increasing and $\pi_r(\xi) \geq 0$ for $\xi \in [0,1]$, collaborative consumption would take place if there exists $\theta \in (0,1)$ such that

$$\pi_o(\theta) = \pi_r(\theta). \tag{3}$$

The parameter θ would then segment the population into owners and renters, where individuals with $\xi > \theta$ are owners and individuals with $\xi < \theta$ are renters (an individual with $\xi = \theta$ is indifferent between owning and renting). We refer to $\omega = \int_{[\theta,1]} f(\xi)\, d\xi$, the fraction of owners in the population, as the *ownership level* or simply *ownership*. In addition, we refer to $q(\theta) = \int_{[\theta,1]} \xi f(\xi)\, d\xi + \beta \int_{[0,\theta]} \xi f(\xi)\, d\xi$, the total usage generated from the population, as the *usage level* or simply *usage*. Note that the first term is usage due to owners, and the second term is usage due to renters (and hence modulated by β).

3.1. Matching Supply with Demand

In the presence of collaborative consumption, let $D(\theta)$ denote the aggregate demand (for rentals) generated by renters and $S(\theta)$ the aggregate supply generated by owners, for given θ. Then, $D(\theta) = \int_{[0,\theta)} \xi f(\xi)\, d\xi$ and $S(\theta) = \int_{[\theta,1]} (1-\xi) f(\xi)\, d\xi$. Moreover, the amount of demand from renters that is fulfilled must equal the amount of supply from owners that is matched with renters. In other words, the following fundamental relationship must be satisfied

$$\alpha S(\theta) = \beta D(\theta). \tag{4}$$

The parameters α and β, along with θ, are determined endogenously in equilibrium.

As mentioned earlier, matching friction can arise because of short-term fluctuations in supply and demand (even though overall supply and demand are constant in the long run). This short-term fluctuation may be due to the inherent variability in the timing of individual rental requests or in the duration of individual rental periods. Consequently, an available product may not find an immediate renter and a renter may not always be able to find an available product. In constructing a model for α and β, the following are desirable properties: (i) α (β) increases (deceases) in θ; (ii) α approaches 1 (0) when θ approaches 1 (0); (iii) β approaches 1 (0) when θ approaches 0 (1), and (iv) α and β must satisfy the supply-demand relationship in (4).

Below we describe a plausible model for the short-term dynamics of matching owners and renters. This model is by no means unique and in Online

Appendix D we describe an alternative approach to model these dynamics. The model takes the view that in the short-term (e.g., over the course of a day) demand is not realized all at once but requests for rentals arise continuously over time with random interarrival times. The intensity of the arrival process is of course determined by the total demand (e.g., total demand per day). The supply translates into individual products available for rent (for simplicity assume that supply is realized all at once and does not fluctuate over the time during which rental requests arrive). Once a product is rented, it becomes unavailable for the duration of the rental time, which may also be random. Because of the randomness in the interarrival times between requests and rental times per request, a request may arrive and find all products rented out. Assuming renters do not wait for a product to become available, such a request would then go unfulfilled. Also, because of this randomness, a product may not be rented all the time even if total demand exceeds total supply.

The dynamics described above are similar to those of a *multi-server loss queueing system*.[7] In such a system, $1-\beta$ would correspond to the *blocking* probability (the probability that a rental request finds all products rented out, or, in queueing parlance, the arrival of a request finds all servers busy) while α would correspond to the utilization of the servers (the probability that a product is being rented out).

If we let m denote the mean rental time per rental, the arrival rate (in terms of rental requests per unit time) is given by $\lambda(\theta)=D(\theta)/m$, and service capacity (the number of rental requests that can be fulfilled per unit time) by $\mu(\theta)=S(\theta)/m$.[8] Therefore, we can express the workload (the ratio of the arrival rate to the service capacity) of the system as $\rho(\theta)=\lambda(\theta)/\mu(\theta)=D(\theta)/S(\theta)$ and the utilization as $\alpha=\beta\lambda(\theta)/\mu(\theta)=\beta D(\theta)/S(\theta)$ (these relationships are of course consistent with the supply-demand relationship in (4)).

Assuming that we can approximate the arrival process by a Poisson process (this is a reasonable assumption given that the arrival process arises from a continuum of renters who make independent decisions about when to seek a rental), the blocking probability, $1-\beta$, can be approximated by $1-1/(1+\rho)$ (see Online Appendix C for details). This leads to the following approximation of α and β

$$\alpha=\frac{\rho}{1+\rho}=\frac{D(\theta)}{S(\theta)+D(\theta)} \tag{5}$$

and

$$\beta=\frac{1}{1+\rho}=\frac{S(\theta)}{S(\theta)+D(\theta)}. \tag{6}$$

Note that α and β, as specified in the above expressions, satisfy the properties (i)–(iv) described above. Interestingly, these expressions can also be obtained directly from the supply-demand relationship in (4) if we require that $\alpha+\beta=1$ ((5) and (6) are in that case the unique solution to (4)).

The expressions in (5) and (6) allow for both α and β to be strictly less than one and for the possibility of matching friction for both owners and renters. In the rest of the paper, we rely on this approximation for our analysis. As mentioned earlier, the model for α and β specified by these expressions is not unique in satisfying properties (i)–(iv).[9] We expect other plausible models that satisfy these properties to lead to results that are qualitatively similar to those we describe in the next two sections.

We are now ready to proceed with the analysis of the equilibrium. An equilibrium under collaborative consumption exists if there exists $(\theta,\alpha)\in(0,1)^2$ that is a solution to (3) and (5). When it exists, we denote this solution by (θ^*,α^*). Knowing the equilibrium allows us to answer important questions regarding product ownership, usage, and social welfare, among others.

4. Equilibrium Analysis

In this section, we consider the case where the price is exogenously specified. In Section 5, we treat the case where the price is chosen optimally by the platform. As mentioned in Section 3, the rental price must satisfy $d_o/(1-\gamma)\le p\le 1-d_r$, since otherwise, either the owners or renters will not participate. We denote the set of admissible prices by $A=[d_o/(1-\gamma),1-d_r]$. For ease of exposition and to allow for closed-form expressions, we assume that ξ is uniformly distributed in $[0,1]$ (we consider more general distributions in Section 6).

Letting θ denote the solution to $\pi_o(\xi)=\pi_r(\xi)$ leads to

$$\theta=\frac{c-((1-\gamma)p-d_o)\alpha}{p+d_r+(1-p-d_r)\alpha-((1-\gamma)p-d_o)\alpha}. \tag{7}$$

Given θ, the aggregate demand under collaborative consumption is given by $D(\theta)=\theta^2/2$ and the aggregate supply by $S(\theta)=(1-\theta)^2/2$. This leads to $\rho(\theta)=\theta^2/(1-\theta)^2$, and by (5)

$$\alpha=\frac{\theta^2}{(1-\theta)^2+\theta^2}. \tag{8}$$

An equilibrium exists if Equations (7) and (8) admit a solution (θ^*,α^*) in $(0,1)^2$.

In the following theorem, we establish the existence and uniqueness of such an equilibrium. Let $\Omega=\{(p,\gamma,c,d_o,d_r)\mid c\in(0,1),\gamma\in[0,1),(d_o,d_r)\in[0,1]^2, p\in A\}$.

Theorem 1. *A unique equilibrium (θ^*,α^*) exists for each $(p,\gamma,c,d_o,d_r)\in\Omega$. Moreover, θ^* and α^* both* (i) *strictly increase with the cost of ownership c, commission rate γ, and extra wear and tear cost d_o, and* (ii) *strictly decrease with rental price p and inconvenience cost d_r.*

The existence of the equilibrium is guaranteed by the Intermediate Value Theorem. The uniqueness is due to the monotonicity of (7) and (8); see Online Appendix B for a proof of this and all subsequent results.

Let ω^* and q^* denote the corresponding ownership and total usage in equilibrium. Then, $\omega^* = 1 - \theta^*$ and $q^* = (1 - \alpha^*\theta^{*2})/2$, where the expression for q^* follows from noting that $q^* = \int_{[\theta^*,1]} \xi\, d\xi + \beta \int_{[0,\theta^*]} \xi\, d\xi$ (note that total usage is the sum of usage from the owners and the fraction of usage from the nonowners that is satisfied through renting).

The following proposition describes how ownership and usage in equilibrium vary with the problem's parameters.

Proposition 2. *In equilibrium, ownership ω^* and usage q^* both strictly increase in price p and inconvenience cost d_r, and strictly decrease in cost of ownership c, commission rate γ, and extra wear and tear cost d_o.*

While the monotonicity results in Proposition 2 are perhaps expected, it is not clear how ownership and usage under collaborative consumption compare to those under no collaborative consumption. In the following subsection, we provide comparisons between systems with and without collaborative consumption, and address the questions of whether or not collaborative consumption reduces product ownership and usage.

4.1. Impact of Collaborative Consumption on Ownership and Usage

In the absence of collaborative consumption, an individual would own a product if $u(\xi) \geq c$ and would not otherwise. Let $\hat{\theta}$ denote the solution to $u(\xi) = c$. Then, the fraction of the population that corresponds to owners (ownership) is given by $\hat{\omega} = \int_{[\hat{\theta},1]} f(\xi)\, d\xi = 1 - c$, with an associated usage given by $\hat{q} = \int_{[\hat{\theta},1]} \xi f(\xi)\, d\xi = (1 - c^2)/2$.

In the following proposition, we compare ownership level with and without collaborative consumption. Without loss of generality, we assume here (and in the rest of the paper) that $d_o/(1-\gamma) < 1 - d_r$ so that the set of admissible prices consists of more than a single price.

Proposition 3. *There exists $p_\omega \in (d_o/(1-\gamma), 1 - d_r)$ such that $\omega^* = \hat{\omega}$ if $p = p_\omega$, $\omega^* < \hat{\omega}$ if $p < p_\omega$, and $\omega^* > \hat{\omega}$ otherwise. Moreover, $\partial p_\omega/\partial \gamma > 0$, $\partial p_\omega/\partial c < 0$, $\partial p_\omega/\partial d_o > 0$, and $\partial p_\omega/\partial d_r < 0$.*

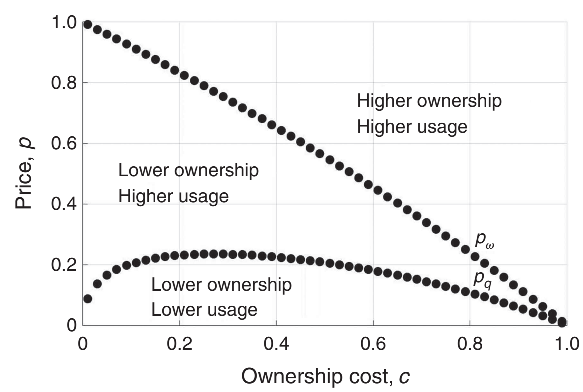
Proposition 3 shows that depending on the rental price p, collaborative consumption can result in either lower or higher ownership. In particular, when the rental price p is sufficiently high (above the threshold p_ω), collaborative consumption leads to higher ownership (e.g., more cars). Moreover, the threshold p_ω is decreasing in the cost of ownership c and renter's inconvenience d_r, and increasing in the commission rate γ and extra wear and tear cost d_o. The fact that p_ω is decreasing in c is perhaps surprising as it shows that collaborative consumption is more likely to lead to more ownership (and not less) when the cost of owning is high. This can be explained as follows. In the absence of collaborative consumption, when the cost of ownership is high, there are mostly nonowners. With the introduction of collaborative consumption, owning becomes more affordable as rental income subsidizes the high cost of ownership. In that case, even at low rental prices, there are individuals (those with high usage) who would switch to being owners. This switch is made more attractive by the high probability of finding a renter (given the high fraction of renters in the population). On the other hand, when the cost of ownership is low, only individuals with low usage are nonowners. For collaborative consumption to turn these nonowners into owners and lead to higher ownership, the rental price needs to be high. This is also needed to compensate for the low probability of finding a renter.

Similarly, usage can be either lower or higher with collaborative consumption than without it. In this case, there is again a price threshold p_q above which usage is higher with collaborative consumption, and below which usage is higher without collaborative consumption. When either d_o or d_r is sufficiently high, collaborative consumption always leads to higher usage. The result is formally stated in Proposition 4.

Proposition 4. *There exists $t \in (0,1)$ such that* (i) *if $d_o/(1-\gamma) + d_r < t$, then there exists $p_q \in (d_o/(1-\gamma), 1-d_r)$ such that $q^* = \hat{q}$ if $p = p_q$, $q^* < \hat{q}$ if $p < p_q$, and $q^* > \hat{q}$ if $p > p_q$;* (ii) *otherwise, $q^* \geq \hat{q}$ for all $p \in [d_o/(1-\gamma), 1-d_r]$.*

Unlike p_ω, the price threshold p_q is not monotonic in c (see Figure 1). As c increases, p_q first increases then decreases. To understand the reason, note that collaborative consumption can lead to higher usage due to the new usage from nonowners. On the other hand, it can

Figure 1. Ownership and Usage for Varying Rental Prices and Ownership Costs (Higher/Lower Ownership/Usage Is Relative to the Case Without Collaborative Consumption; $\gamma = 0.2$, $d_o = d_r = 0$)



lead to lower usage if ownership decreases sufficiently (certainly to a level lower than that without collaborative consumption) such that the decrease in usage from those who switch from owning to renting is larger than the increase in usage from those who are nonowners. This implies that lower usage is less likely to happen if either (i) the individuals who switch from owning to renting can fulfill most of their usage via renting or (ii) the usage from nonowners is high. The first scenario is true when the population of owners is high (i.e., the cost of ownership is low), whereas the second scenario is true when the population of nonowners is high (i.e., cost of ownership is high). Therefore, collaborative consumption is less likely to lead to lower usage when the cost of ownership is either very low or very high. Hence, the threshold p_q is first increasing then decreasing in c. When the cost of ownership is moderate, there is a balance of owners and nonowners without collaborative consumption, allowing for ownership to sufficiently decrease with relatively moderate rental prices, which in turn leads to lower usage and, correspondingly, a relatively higher threshold p_q.

The following corollary to Propositions 3 and 4 summarizes the joint impact of p and c on ownership and usage.

Corollary 5. *In settings where p_ω and p_q are well defined (per Propositions 3 and 4), collaborative consumption leads to higher ownership and higher usage when $p > p_\omega$, lower ownership but higher usage when $p_q < p \le p_\omega$, and lower ownership and lower usage when $p \le p_q$.*

Corollary 5, along with Propositions 3 and 4, shows how price thresholds p_ω and p_q segment the full range of values of c and p into three regions, in which collaborative consumption leads to (i) lower ownership and lower usage, (ii) lower ownership but higher usage, and (iii) higher ownership and higher usage. These three regions are illustrated in Figure 1. These results highlight the fact that the impact of collaborative consumption on ownership and usage is perhaps more nuanced than what is sometimes claimed by advocates of collaborative consumption. The results could have implications for public policy. For example, in regions where the cost of ownership is high, the results imply that, unless rental prices are kept sufficiently low or the commission extracted by the platform is made sufficiently high, collaborative consumption would lead to more ownership and more usage. This could be an undesirable outcome if there are negative externalities associated with ownership and usage. Higher usage also implies less usage of the outside option (e.g., less use of public transport).

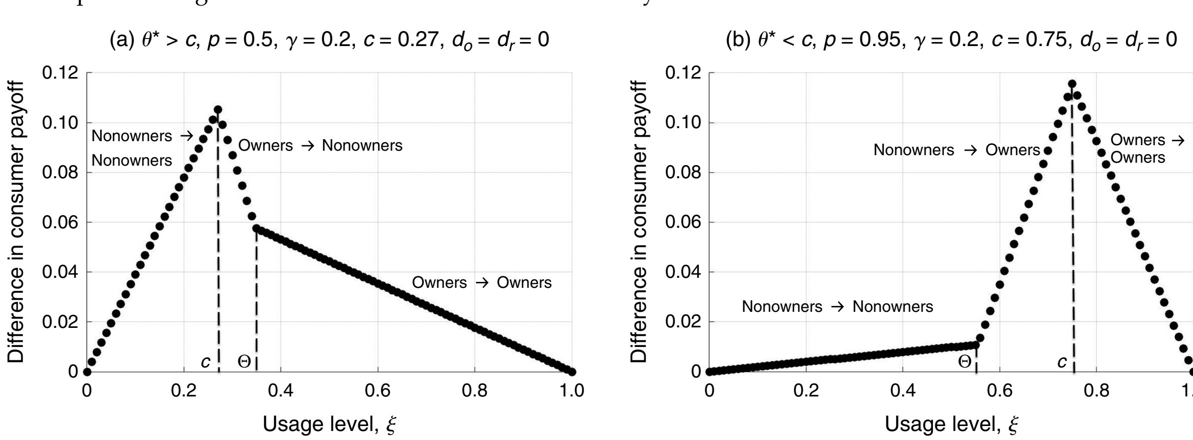
4.2. Impact of Collaborative Consumption on Consumers

Next, we examine the impact of collaborative consumption on consumer payoff. Consumer payoff is of course always higher with the introduction of collaborative consumption (consumers retain the option of either owning or not owning, but now enjoy the additional benefit of earning rental income if they decide to own, or of fulfilling some of their usage through renting if they decide not to own). What is less clear is who, among consumers with different usage levels, benefits more from collaborative consumption.

Proposition 6. *Let $\pi^*(\xi)$ and $\hat{\pi}(\xi)$ denote the consumer payoff with and without collaborative consumption, respectively. Then, the difference in consumer payoff $\pi^*(\xi) - \hat{\pi}(\xi)$ is positive, piecewise linear, strictly increasing on $[0, c)$, and strictly decreasing on $[c, 1]$.*

An important implication from Proposition 6 (from the fact that the difference in consumer surplus $\pi^*(\xi) - \hat{\pi}(\xi)$ is strictly increasing on $[0, c)$ and strictly decreasing on $[c, 1]$) is that consumers who benefit the most from collaborative consumption are those who are indifferent between owning and not owning without collaborative consumption (recall that $[c, 1]$ corresponds to the population of owners in the absence of collaborative consumption). This can be explained by noting that there are always three segments of consumers (see Figure 2). In the case where

Figure 2. Impact of Usage Level on the Difference in Consumer Payoff



$\theta^* \geq c$ (Figure 2(a)), which corresponds to the case where ownership decreases with collaborative consumption, the first segment corresponds to consumers who are nonowners in the absence of collaborative consumption and continue to be nonowners with collaborative consumption (indicated by "nonowners → nonowners" in Figure 2). The benefit these consumers derive from collaborative consumption is due to fulfilling part of their usage through accessing a rented product. This benefit is increasing in their usage.

The second segment corresponds to consumers who are owners in the absence of collaborative consumption and switch to being nonowners with collaborative consumption (indicated by "owners → nonowners"). These consumers have to give up the fulfillment of some usage (because a rental product may not always be available) and the amount they give up is increasing in their usage. Therefore, the amount of benefit they receive from renting decreases in their usage level. The third segment consists of consumers who are owners in the absence of collaborative consumption and continue to be owners with collaborative consumption (indicated by "owners → owners"). The benefit they experience is due to rental income. This income is decreasing in their usage (they have less capacity to rent when they have more usage). A similar explanation can be provided for the case where $\theta^* < c$ (Figure 2(b)).

5. The Platform's Problem

In this section, we consider the problem faced by the platform. We first consider the case of a for-profit platform whose objective is to maximize the revenue from successful transactions. Then, we consider the case of a not-for-profit platform (e.g., a platform owned by a nonprofit organization, government agency, or municipality) whose objective is to maximize social welfare.[10] We compare the outcomes of these platforms in terms of ownership, usage, and social welfare. We also benchmark the social welfare of these platforms against the maximum feasible social welfare.

A platform may decide, among others, on the price and commission rate. In this section, we focus on price as the primary decision made by the platform and treat other parameters as being exogenously specified (a survey of major peer-to-peer car-sharing platforms worldwide reveals that commission rates fall mostly within a relatively narrow range, from 30% to 40% for those that include insurance, and do not typically vary across markets in which platforms operate). There are of course settings where the price is a decision made by the owners. Price may then be determined through a market-clearing mechanism (i.e., the price under which supply equals demand; see Jiang and Tian 2018). In our case, because of the friction in matching supply and demand, the supply–demand balance equation in (4) can, per Theorem 1, be satisfied by any feasible price. Thus, the market-clearing price is not unique, and the system may settle on a price that maximizes neither social welfare nor platform revenue. Moreover, as we show in Section 5.1, platform revenue (or social welfare) can be highly sensitive to price, giving the platform an incentive to optimize price. Platform pricing may also be beneficial to owners as it can serve as a coordinating tool and reduce competition among them. More significantly, and as we show in Section 5.2, the social welfare that results from a for-profit platform tends to be close to that resulting from a not-for-profit platform.

In what follows, we provide detailed analysis for the for-profit and not-for-profit platforms under the assumptions of Section 4. In Sections 5.1–5.3, we consider the case where $(d_o, d_r) = (0,0)$. In Section 5.4, we discuss the case where $(d_o, d_r) \neq (0,0)$.

5.1. The For-Profit Platform

For a for-profit platform, the objective is to maximize $\gamma p \alpha S(\theta)$, the commission income generated from the fraction of supply that is matched with demand. In particular, the platform's optimization problem can be stated as follows:

$$\underset{p}{\text{maximize}} \quad v_r(p) = \gamma p \alpha S(\theta) \tag{9}$$

$$\text{subject to} \quad \pi_o(\theta) = \pi_r(\theta), \tag{10}$$

$$\alpha = \frac{D(\theta)}{D(\theta) + S(\theta)}, \tag{11}$$

$$\frac{d_o}{1-\gamma} \leq p \leq 1 - d_r. \tag{12}$$

The constraints (10) and (11) are the defining equations for the equilibrium (θ^*, α^*). The constraint (12) ensures that price is in the feasible set A. In what follows, we assume that $\gamma > 0$ (the platform's revenue is otherwise always zero).

Under the assumptions of Section 4, the for-profit platform's problem can be restated as follows:

$$\underset{p}{\text{maximize}} \quad v_r(p) = \tfrac{1}{2}\gamma p \alpha (1-\theta)^2 \tag{13}$$

subject to (7) and (8) and $p \in A$. It is difficult to analyze (13) directly. However, as the map between θ and p is bijective, we can use (7) and (8) to express p in terms of θ as

$$p(\theta) = \frac{-\theta^3 + 2c\theta^2 - 2c\theta + c}{\theta(\theta-1)(\gamma\theta - 1)}. \tag{14}$$

Hence, (13) can be expressed as

$$\underset{\theta}{\text{maximize}} \quad v_r(\theta) = \frac{\gamma}{2} \frac{(1-\theta)\theta(\theta^3 - 2c\theta^2 + 2c\theta - c)}{((1-\theta)^2 + \theta^2)(\gamma\theta - 1)} \tag{15}$$

$$\text{subject to} \quad \theta \in [\underline{\theta}, \bar{\theta}],$$

where $\underline{\theta}$ is the solution to (7) and (8) at $p = 1$, $\bar{\theta}$ is the solution at $p = 0$, and $[\underline{\theta}, \bar{\theta}]$ is the set of solutions induced by $p \in [0,1]$. We can use (14) to verify whether θ is in $[\underline{\theta}, \bar{\theta}]$. Specifically, $\theta < \underline{\theta}$ if $p(\theta) > 1$, $\theta \in [\underline{\theta}, \bar{\theta}]$ if $p(\theta) \in [0,1]$, and $\theta > \bar{\theta}$ if $p(\theta) < 0$.

Proposition 7. *$v_r(\theta)$ is strictly quasi-concave in θ.*

Proposition 7 shows that the platform's problem is not difficult to solve. Depending on the value of γ and c, $v_r(\theta)$ is either decreasing or first increasing then decreasing on $[\underline{\theta}, \bar{\theta}]$. In both cases, the optimal solution to (15), which we denote by θ_r^*, is unique. We let p_r^*, ω_r^*, and q_r^* denote the corresponding price, ownership, and usage, respectively. We also use the notation v_r^* to denote the optimal revenue $v_r(\theta_r^*)$.

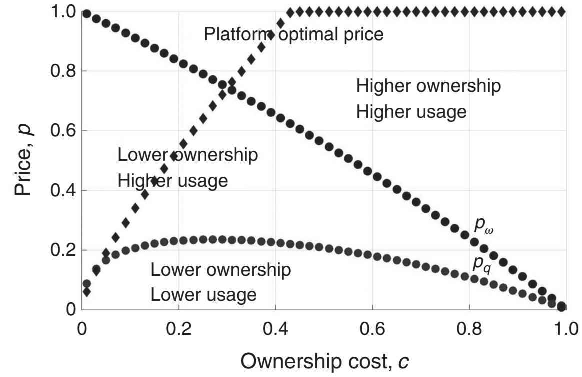
Proposition 8. *The platform's optimal revenue, v_r^*, is strictly quasi-concave in c, first strictly increasing and then strictly decreasing.*

Proposition 8 suggests that a platform would be most profitable when the cost of ownership is "moderate" and away from the extremes of being either very high or very low. In these extreme cases, not enough transactions take place because of either not enough renters (when the cost of ownership is low) or not enough owners (when the cost of ownership is high). This is perhaps consistent with the experience of iCarsClub, a peer-to-peer car-sharing platform, that was first launched in Singapore, a country where the cost of ownership is exceptionally high and car ownership is low. iCarsClub struggled in Singapore and had to temporarily suspend operations. However, it is thriving in China where it operates under the name PPzuche and is present in several cities (Clifford Teo, CEO of iCarsClub, personal communication, 2015). This result also implies that a platform may have an incentive to affect the cost of ownership. For example, when the cost of ownership is low, a platform may find it beneficial to impose a fixed membership fee on owners, increasing the effective cost of ownership. On the other hand, when the cost of ownership is high, the platform may find it beneficial to lower the effective cost of ownership by offering, for example, subsidies (or assistance with financing) toward the purchase of new products.

Proposition 9. *There exists a threshold $c_{r,\omega} \in (0,1)$ such that optimal ownership $\omega_r^* = \hat{\omega}$ if $c = c_{r,\omega}$, $\omega_r^* < \hat{\omega}$ if $c < c_{r,\omega}$, and $\omega_r^* > \hat{\omega}$ otherwise, with $c_{r,\omega}$ strictly increasing in γ.*

Proposition 9 shows that it continues to be possible, even when the price is chosen optimally by a revenue maximizing platform, for collaborative consumption to lead to either higher or lower ownership. In particular, collaborative consumption leads to higher ownership when the cost of ownership is sufficiently high (above the threshold $c_{r,\omega}$) and to lower ownership when the cost of ownership is sufficiently low (below the threshold $c_{r,\omega}$). This can be explained as follows. The platform has an incentive to somewhat balance supply and demand (otherwise, few rentals will take place). When the cost of ownership is high, ownership is low in the absence of collaborative consumption. In this case, the platform would try to induce, via higher prices, higher ownership, so as to generate more supply (hence, the result that a sufficiently high cost of ownership leads to higher ownership under collaborative consumption).[11] Similarly, when the cost of ownership is low, the platform would try to induce lower ownership via lower prices, so as to generate more demand (hence, the result that a sufficiently low cost of ownership leads to low ownership under collaborative consumption).

Figure 3. Impact of Ownership Cost on Ownership and Usage (Higher/Lower Ownership/Usage Is Relative to the Case Without Collaborative Consumption; $\gamma = 0.2$, $d_o = d_r = 0$)



We also observe that usage under platform pricing can be either higher or lower than that without collaborative consumption. Again, there exists a threshold $c_{r,q} < c_{r,\omega}$ in the cost of ownership, below which collaborative consumption leads to lower usage and above which collaborative consumption leads to higher usage. The impact of ownership cost on product ownership and usage under platform pricing is illustrated in Figure 3 (the platform optimal price corresponds to the curve marked with the diamond symbol).

5.2. The Not-for-Profit Platform

For a not-for-profit platform, the objective is to maximize social welfare (i.e., the sum of consumer surplus and platform revenue). Thus, the platform's problem can be stated as

$$\underset{p}{\text{maximize}}\ v_s(p) = \int_{[\theta,1]} (\xi - c) f(\xi)\, d\xi + \int_{[0,\theta)} \beta \xi f(\xi)\, d\xi \quad (16)$$

subject to constraints (10)–(12).

Under the assumptions of Section 4, the platform's problem can be restated as follows:

$$\underset{p}{\text{maximize}}\ v_s(p) = \tfrac{1}{2}(1 - \alpha\theta^2) - (1 - \theta)c \quad (17)$$

subject to (7) and (8) and $p \in A$, or equivalently as

$$\begin{aligned} &\underset{\theta}{\text{maximize}} \quad v_s(\theta) = \frac{1}{2}\left(1 - \frac{\theta^4}{(1-\theta)^2 + \theta^2}\right) - (1-\theta)c \\ &\text{subject to} \quad \theta \in [\underline{\theta}, \bar{\theta}]. \end{aligned} \tag{18}$$

Analysis and results similar to those obtained for the for-profit platform can be obtained for the not-for-profit platform. In particular, we can show that the social welfare function, v_s, is strictly concave in θ, indicating that computing the optimal solution for the not-for-profit platform is also not difficult (we omit the details for the sake of brevity). The result also implies that (18) admits a unique optimal solution, which we denote by θ_s^*, with a resulting optimal social welfare, which we denote by v_s^*.

The following proposition characterizes θ_s^* for varying values of γ.

Proposition 10. *There exists a strictly positive decreasing function $\gamma_s(c)$ such that $\theta_s^* \in (\underline{\theta}, \bar{\theta})$ if $\gamma < \gamma_s$, and $\theta_s^* = \underline{\theta}$ otherwise. Consequently, if $\gamma \le \gamma_s(c)$, then*

$$\max_{\theta \in [\underline{\theta}, \bar{\theta}]} v_s = \max_{\theta \in [0,1]} v_s.$$

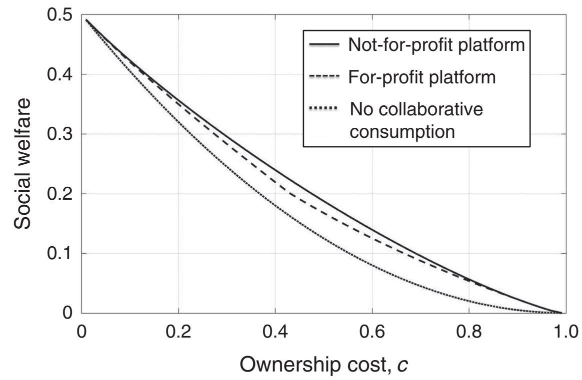
Proposition 10 shows that θ_s^* is an interior solution (satisfying $(\partial v_s/\partial\theta)(\theta_s^*) = 0$) if the commission rate is sufficiently low (below the threshold γ_s). Otherwise, it is the boundary solution $\underline{\theta}$. In particular, θ_s^* could never take the value of $\bar{\theta}$. An important implication of this result is that, when $\gamma < \gamma_s$, a not-for-profit platform that relies on price alone as a decision variable would be able to achieve the maximum feasible social welfare (i.e., the social welfare that would be realized by a social planner who can directly decide on the fraction of nonowners, θ). Note that this is especially true if the not-for-profit platform does not charge a commission rate (i.e., $\gamma = 0$).

Similar to the case of the for-profit platform, we can also show that a not-for-profit platform can lead to either higher or lower ownership or usage (relative to the case without collaborative consumption). Again, there are thresholds $c_{s,q} < c_{s,\omega}$ in the cost of ownership such that (i) ownership and usage are both lower if $c \le c_{s,q}$, (ii) ownership is lower but usage is higher if $c_{s,q} < c \le c_{s,\omega}$, and (iii) ownership and usage are both higher if $c > c_{s,\omega}$.

In the following proposition, we compare outcomes under the for-profit and not-for-profit platforms. In particular, we show that a not-for-profit platform would always charge a lower price than a for-profit platform. Therefore, it would also induce lower ownership and lower usage.

Proposition 11. *Let p_s^*, ω_s^*, and q_s^* denote the optimal price, ownership, and usage levels under a not-for-profit platform, respectively. Then, $p_s^* \le p_r^*$, $\omega_s^* \le \omega_r^*$, and $q_s^* \le q_r^*$.*

Figure 4. Impact of Ownership Cost on Social Welfare ($\gamma = 0.2$, $d_o = d_r = 0$)



A not-for-profit platform induces lower ownership by charging lower prices because it accounts for the negative impact of the cost of ownership on social welfare. In settings where there are negative externalities associated with ownership and usage, the result in Proposition 11 shows that, even without explicitly accounting for these costs, the not-for-profit platform would also lower such externalities (since both ownership and usage are lower). The fact that social welfare is maximized at prices lower than those that would be charged by a for-profit platform suggests that a regulator may be able to nudge a for-profit platform toward outcomes with higher social welfare by putting a cap on price.

Figure 4 illustrates the differences in social welfare between a system without collaborative consumption and systems with collaborative consumption under (a) a for-profit platform (a revenue-maximizing platform) and (b) a not-for-profit platform (a social-welfare–maximizing platform). Systems with collaborative consumption can improve social welfare substantially, especially when the cost of ownership is neither too high nor too low (in those extreme cases, there are either mostly owners or mostly renters and, therefore, few transactions). However, the differences in social welfare between the for-profit and not-for-profit platforms are not very significant. This is because both platforms have a similar interest in maintaining a relative balance of renters and owners.

5.3. Systems with Negative Externalities

In this section, we consider settings where there are negative externalities associated with either usage or ownership. In that case, social welfare must account for the additional cost of these externalities. In particular, the following additional terms must be subtracted from the expression of social welfare in (16)

$$e_q q(\theta) + e_\omega \omega(\theta), \tag{19}$$

or equivalently

$$e_q\left(\int_{[\theta,1]}\xi f(\xi)\,d\xi+\beta\int_{[0,\theta)}\xi f(\xi)\,d\xi\right)+e_\omega\int_{[\theta,1]}f(\xi)\,d\xi, \tag{20}$$

where e_q and e_ω correspond to the social (or environmental) cost per unit of usage and per unit of ownership, respectively. This is consistent with the so-called *lifecycle* approach to assessing the social impact of using and owning products (see, for example, Reap et al. 2008). The parameter e_q accounts for the social (or environmental) cost of using a product not captured by the utility (e.g., the cost of pollution associated with using a product), while e_ω would account for the social cost of product manufacturing, distribution, and end-of-life disposal.

For a not-for-profit platform, the optimization problem can then be restated as

$$\begin{aligned}\underset{\theta}{\text{maximize}}\quad & v_e(\theta)=\frac{1}{2}(1-e_q)\left(1-\frac{\theta^4}{(1-\theta)^2+\theta^2}\right)\\ &\qquad -(c+e_\omega)(1-\theta)\\ \text{subject to}\quad & \theta\in[\underline{\theta},\bar{\theta}].\end{aligned} \tag{21}$$

It is easy to show that the modified social welfare function v_e is still strictly quasi-concave in θ. Moreover, the optimal solution, which we denote by θ_e^*, is strictly increasing in both e_q and e_ω. As a result, the ownership and usage levels obtained under $e_q>0$ and $e_\omega>0$ are lower than those obtained under $e_q=e_\omega=0$. Therefore, Proposition 11 continues to hold. However, Proposition 10 may no longer be valid if either e_q or e_ω is too large. That is, the platform may not be able to achieve the maximum feasible social welfare even if the commission rate is negligible. In this case, to achieve a higher social welfare, the platform may need to either subsidize nonowners (e.g., improve rental experience by reducing inconvenience cost) or penalize owners (e.g., make the ownership cost higher by charging extra tax on ownership), in addition to setting a low rental price.

We conclude this section by addressing the question of whether collaborative consumption reduces the total cost of negative externalities, $e_q q(\theta)+e_\omega\omega(\theta)$. Recall that collaborative consumption (under either a for-profit or a not-for-profit platform) leads to lower ownership and lower usage when the cost of ownership is sufficiently low, and it leads to higher ownership and higher usage when the cost of ownership is sufficiently high (see Figure 3). This implies that collaborative consumption could either decrease or increase negative externalities, with a decrease more likely when the cost of ownership is low. In numerical experiments, we observe that there exists a threshold on the cost of ownership, which we denote by c_e, such that collaborative consumption reduces negative externalities if and only if $c<c_e$. We also observe that c_e is decreasing in e_q and increasing in e_ω, indicating that collaborative consumption is more likely to reduce negative externalities if the social (or environmental) cost of using products is relatively low compared to that of owning.

5.4. The Impact of Extra Wear and Tear and Inconvenience Costs

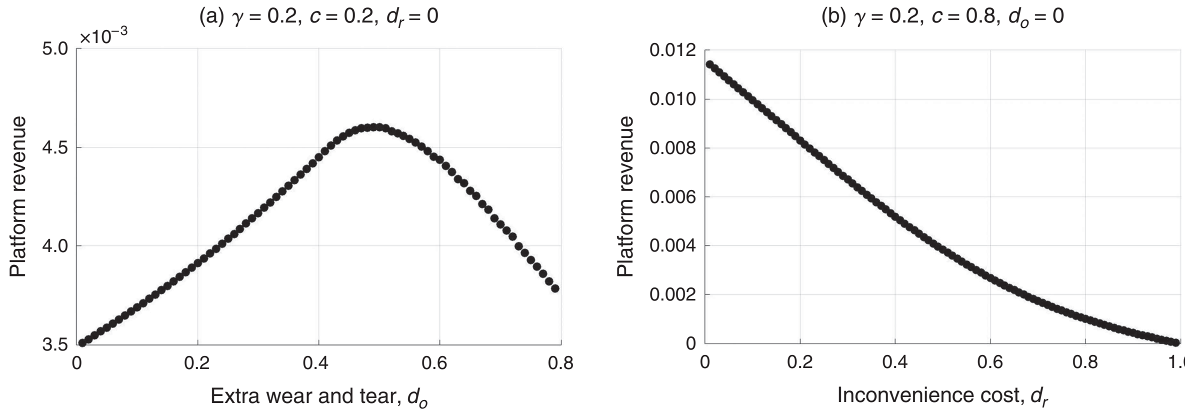
In this section, we consider the case where $(d_o,d_r)\neq 0$. The extra wear and tear cost d_o reduces the payoff of owners and, therefore, places a lower bound on the set of admissible prices: $p\geq d_o/(1-\gamma)$. Similarly, the inconvenience cost d_r reduces the payoff of renters and, consequently, places an upper bound on the price: $p\leq 1-d_r$. Obtaining analytical results is difficult. However, we are able to confirm numerically that all the results obtained for $(d_o,d_r)=0$ continue to hold (details are omitted for brevity).

Of additional interest is the impact of d_o and d_r on platform revenue and social welfare. For both the for-profit and not-for-profit platforms, we observe that social welfare is decreasing in both d_o and d_r. This is consistent with intuition. However, revenue for the for-profit platform can be nonmonotonic in d_o. In particular, when the cost of ownership is low, platform revenue can first increase then decrease with d_o. This effect appears related to the fact that platform revenue is, per Proposition 8, nonmonotonic in the cost of ownership. A higher value of d_o can be beneficial to the platform if it helps balance the amount of owners and renters (i.e., reduce ownership), leading to a greater amount of transactions. An implication from this result is that between two platforms, the one with the higher wear and tear cost (everything else being equal) can be more profitable. The result also implies that a for-profit platform may not always have an incentive to reduce this cost. Note that, in some cases, a platform could exert costly effort to reduce this cost. For example, when extra wear and tear is, in part, due to renters' negligence, more effort could be invested in the vetting of would-be renters. Alternatively, the platform could provide more comprehensive insurance coverage or monitor more closely the usage behavior of a renter (such monitoring technology is already available for example in the case of cars). On the other hand, the inconvenience cost d_r does not have the same effect on platform revenue. An increase in d_r could lead to more transactions. However, it limits the price a platform could charge. The net effect is that the platform revenue is always decreasing in d_r. These effects are illustrated in Figure 5.

6. Extensions

In this section, we examine the robustness of our results by extending the analysis to two important settings: (1) a setting where nonowners, in addition to renting from individual owners, have the option of

Figure 5. Platform Revenue for Varying Extra Wear and Tear and Inconvenience Costs



renting from a third-party service provider and (2) a setting where the platform, in addition to matching owners and nonowners, can also own products that it puts out for rent. In each case, we examine how collaborative consumption affects ownership and usage, and how these outcomes vary from those observed in the original model. We briefly discuss other extensions and generalizations. In particular, we consider cases where (1) the extra wear and tear and inconvenience costs are heterogeneous among individuals; (2) usage, instead of being exogenously specified, is a decision individuals make; and (3) usage is exogenous but has a general distribution.

6.1. Systems with a Third-Party Service Provider

In this section, we consider a setting where the outside option for nonowners includes renting through a third-party service provider. The service provider (e.g., a car rental service) owns multiple units of the product that they make available for rent. We let $\tilde{p}$ denote the rental price and $\tilde{d}_r$ the inconvenience cost incurred by a renter when using the service (we use "~" throughout to indicate the parameters for the third-party service provider). We allow for the possibility that the service is not always reliable, and we denote the fraction of time that a product is available for rent from the service provider when requested by a renter by $\tilde{\beta}$. We refer to $\tilde{\beta}$ as the *service level* of the service provider. As in the original model, we focus on the case where the utility function $u(\xi) = \xi$ and individual usage ξ follows a uniform distribution.

In the case of no collaborative consumption (i.e., peer-to-peer product sharing is not available), individuals have the option of either owning the product or renting it through the service provider. An owner with usage level ξ has payoff $\tilde{\pi}_o(\xi) = \xi - c$, while a renter has payoff $\tilde{\pi}_r(\xi) = \tilde{\beta}(1 - \tilde{p} - \tilde{d}_r)\xi$. Let

$$\tilde{\theta} = \begin{cases} \dfrac{c}{\tilde{p} + \tilde{d}_r + (1 - \tilde{p} - \tilde{d}_r)(1 - \tilde{\beta})} & \text{if } \tilde{\beta} \le \dfrac{1 - c}{1 - \tilde{p} - \tilde{d}_r}, \\ 1 & \text{otherwise.} \end{cases}$$

Then, individuals with usage $\xi < \tilde{\theta}$ choose to be renters, those with usage $\xi > \tilde{\theta}$ choose to be owners, and those with usage $\xi = \tilde{\theta}$ are indifferent between renting and owning. Note that when the service level is sufficiently high ($\tilde{\beta} \ge (1 - c)/(1 - \tilde{p} - \tilde{d})$), there are no owners and everyone chooses to rent. The threshold above which the service level must be for this to occur is decreasing in the cost of ownership and increasing in the rental price and inconvenience cost.

In the presence of collaborative consumption, we assume that consumers always prefer peer-to-peer product sharing over renting through the service provider.[12] That is, we require $p + d_r \le \tilde{p} + \tilde{d}_r$. A consumer would then seek to rent from the service provider when no product is available through peer-to-peer product sharing. An owner with usage ξ has payoff $\pi_o(\xi) = \xi + (1 - \xi)\alpha((1 - \gamma)p - d_o) - c$, while that of a renter is given by $\pi_r(\xi) = \beta(1 - p - d_r)\xi - (1 - \beta)\tilde{\beta}(1 - \tilde{p} - \tilde{d}_r)\xi$. We can show that an equilibrium (θ^*, α^*) under collaborative consumption exists and is unique for each feasible combination of problem parameters if and only if $\tilde{\beta} < (1 - c)/(1 - \tilde{p} - \tilde{d}_r)$ (see Online Appendix E for details). In other words, peer-to-peer product sharing can coexist in equilibrium with a third-party service provider as long as the service level offered by the service provider is sufficiently low ($\tilde{\beta} < (1 - c)/(1 - \tilde{p} - \tilde{d})$). Otherwise, all individuals would prefer renting through the service provider to owning.

As with the original model in Section 3, we can show that ownership ω^* and usage q^* still increase in p, d_r (also in $\tilde{p}$ and $\tilde{d}_r$) but decrease in c, γ, and d_o. Similar to the case of no collaborative consumption, ownership decreases in the service level $\tilde{\beta}$, but usage may first decrease then increase in $\tilde{\beta}$. More importantly, collaborative consumption can still lead to either higher or lower ownership and usage. There are again price thresholds p_ω and p_q that segment the range of values of c and p into three regions in which collaborative consumption leads to (i) lower ownership and lower usage, (ii) lower ownership but higher usage, and (iii) higher ownership and higher usage. The price threshold p_ω is again decreasing in the cost of ownership c, implying that higher ownership is more likely when the cost of ownership is higher. Hence, all of the insights, regarding the impact of collaborative consumption on ownership and usage, continue to be valid. In the case where the platform chooses prices (either to maximize profit or social welfare), there are again thresholds $c_q < c_\omega$ in the cost of ownership such that (i) ownership and usage are both lower if $c \le c_q$, (ii) ownership is lower but usage is higher if $c_q < c \le c_\omega$, and (iii) ownership and usage are both higher if $c \ge c_\omega$.

In addition to confirming results consistent with the original model, we can show that the price thresholds p_ω and p_q are both decreasing in the service level $\tilde{\beta}$. This is perhaps surprising as it implies that collaborative consumption is more likely to lead to higher ownership and usage when the service level offered by the service provider is higher. This can be explained as follows. In the absence of collaborative consumption, a higher service level leads to more renters. Introducing collaborative consumption to a population with a large number of renters makes ownership attractive as the likelihood of finding a renter would be high. Finally, note that the fact that p_ω and p_q are decreasing in the service level $\tilde{\beta}$ implies that these thresholds are lower with a third-party service provider than without one (a system with no service provider can be viewed as one with $\tilde{\beta} = 0$).

6.2. Systems Where the Platform Owns Assets

We have so far assumed that the platform does not own products of its own and that its only source of revenue is from commissions. This is consistent with the observed practice of most existing peer-to-peer product-sharing platforms. Owning physical assets poses several challenges, particularly to startups, including access to capital, managerial know-how, and the need to invest in physical infrastructure (e.g., parking lots and maintenance facilities in the case of cars). Owning, managing, and maintaining physical assets can also limit the ability of some platforms to grow rapidly. More significantly, there can be perceived business risks associated with the ownership of physical assets. Nevertheless, it is conceivable that, as these platforms grow, they can find it profitable to own products of their own. Below, we briefly describe such a setting and examine the implication of product ownership by the platform.

Consider a setting similar in all aspects to the one described in Sections 3 and 4, except that the platform may own products of its own that it puts out for rent. Let S_p and S_o denote, respectively, the amount of supply generated from platform-owned products and individually owned products. Then, the total amount of supply in the system is given by $S = S_p + S_o$. We assume that renters do not differentiate between products owned by the platform and those owned by individuals, with the same rental price applying to both (it is possible of course to consider alternative assumptions where renters may exhibit preferences for one over the other). We also assume that the platform incurs the same ownership cost (per unit of supply) as individual owners (it is easy to relax this assumption by incorporating economies/diseconomies of scale). Then, given the rental price p and level of supply S_p, the platform profit is expressed as $v(p, S_p) = \gamma p \alpha S_o + p\alpha S_p - cS_p$.

The platform now generates revenue from two sources, peer-to-peer rentals and rentals of platform-owned products (the first two terms in the above expression), while incurring the ownership cost for the products it owns (the third term in the expression). For a fixed price, the introduction of platform-owned products makes foregoing ownership more attractive, for the likelihood of successfully renting a product is now higher. Hence, individual ownership decreases and demand for rentals increases. However, it is not clear what the impact is on α (the likelihood of successfully renting out a product) since the increase in rental demand is accompanied by an injection of supply from the platform.

It turns out that, in equilibrium,[13] both the supply due to individual owners S_o and the matching parameter α are decreasing in S_p. This implies that platform revenue from peer-to-peer rentals would be maximized by the platform not owning products. Therefore, for owning products to be optimal, the platform must generate sufficient profit from the products it owns. That is, $p\alpha S_p - cS_p$ must be sufficiently large. A necessary condition for this to occur is for $p\alpha - c > 0$ when $S_p = 0$. Since α is decreasing in S_p, for relatively large values of S_p to be optimal, the price must also be relatively high.

The optimal price p^* and supply level S_p^* are difficult to characterize analytically. However, we observe numerically that the platform would own products (i.e., $S_p^* > 0$) if and only if the commission rate γ and the cost of ownership c are sufficiently large. This is consistent with the discussion above, as $p\alpha - c > 0$ requires both γ (recall that $(1-\gamma)p\alpha - c < 0$ in the presence of collaborative consumption) and p to be large, and a large p is only optimal when c is also large.

In summary, there seems to be a relatively narrow range of parameter values under which a platform finds it optimal to own products, since doing so cannibalizes its revenue from peer-to-peer rentals while reducing the likelihood that products, including its own, find renters. Note also that a platform that owns products must choose price p such that $p > c$. In contrast, a price $p < c$ is feasible for a pure peer-to-peer platform (because owners derive positive utility from using the product, they are willing to rent it for a price $p < c$). Hence, a platform that owns products (or relies exclusively on its own products) may invite competition from pure peer-to-peer platforms that can afford to charge a lower price (this is arguably the competitive advantage of many peer-to-peer sharing platforms).

Finally, we note that, as in the original model, the introduction of a platform (regardless of whether or not it owns products) can lead to either higher or lower ownership/usage, with higher ownership/usage again more likely when the cost of ownership is higher. Under optimal pricing, the platform owns assets only under a narrow range of parameter values. In those cases (i.e., when it owns assets), collaborative consumption leads to more ownership and usage than when it does not.

6.3. Other Extensions and Generalizations

In this section, we briefly describe extensions involving relaxing assumptions we make in the original model. Details can be found in Online Appendix E.2.

6.3.1. Systems with Heterogeneous Extra Wear and Tear and Inconvenience Costs. In the original model, we assumed that individuals are differentiated only by their usage level. Our analysis can be extended to settings where, in addition to usage level, individuals differ in their sensitivity to wear and tear and to inconvenience. That is, individuals are now heterogeneous in their costs d_o and d_r (in addition to their usage level ξ), with the heterogeneity along these three dimensions described by a joint density function. This leads to an equilibrium where those with sufficiently high usage are owners while the rest are nonowners. Among owners, those with sufficiently low sensitivity to wear and tear participate in collaborative consumption by putting their products out for rent, while the rest prefer not to participate. Similarly, among nonowners, those with sufficiently low sensitivity to inconvenience participate in collaborative consumption by always attempting to rent from owners, while the rest prefer to use their outside option instead. As with the original model, collaborative consumption can lead to either higher or lower ownership/usage depending on the cost of ownership.

6.3.2. Systems with Endogenous Usage. In the original model, we assumed that usage is exogenously specified. Our analysis can be extended to the case where usage is a decision that each individual makes. In particular, our analysis can be extended to settings where individuals are heterogeneous in usage valuation and with their utility specified by an increasing concave function in usage. This leads to an equilibrium where individuals with sufficiently high usage valuation own and participate in collaborative consumption, while the rest do not own. Among nonowners, only those with sufficiently high valuation participate in collaborative consumption by renting from those who own, while the rest prefer to use their outside option. Again, as with the original model, collaborative consumption can lead to either higher or lower ownership/usage depending on the cost of ownership.

6.3.3. Systems with General Usage Distribution. Our analysis can be extended to settings where usage level has a general distribution. All of our main results, including those regarding the impact of collaborative consumption on ownership and usage, continue to hold.

7. Concluding Comments

In this paper, we described an equilibrium model of collaborative consumption. We characterized equilibrium outcomes, including ownership and usage levels, consumer surplus, and social welfare. We compared each outcome in systems with and without collaborative consumption and examined the impact of various problem parameters including rental price, platform's commission rate, cost of ownership, owner's extra wear and tear cost, and renter's inconvenience cost. Our findings indicate that collaborative consumption can result in either higher or lower ownership and usage levels, with higher ownership and usage levels more likely when the cost of ownership is high. We showed that consumers always benefit from collaborative consumption, with individuals who, in the absence of collaborative consumption, are indifferent between owning and not owning benefitting the most. We also showed that the platform's profit is not monotonic in the cost of ownership (first increasing and then decreasing), implying that a platform is least profitable when the cost of ownership is either very high or very low (also suggesting that a platform may have an incentive to affect the cost of ownership by, for example, imposing membership fees or providing subsidies). In addition, we observed that, when the cost of ownership is low, platform profit can be increasing in the extra wear and tear cost, suggesting that a for-profit platform may not always have an incentive to eliminate this cost.

Possible avenues for future research are many. We mention a few examples. It would be of interest to consider settings where there is competition among multiple platforms, with owners and renters having the option of participating in one or more such platforms. Given that the effective demand the platform would face is nonmonotonic in price, competition may not necessarily lead (as in a standard competitive setting) to lower prices. In this case, the competing platforms must account for the need to balance, via their choice of prices, the supply of owners and renters. It would also be interesting to investigate other forms of peer-to-peer product sharing, such as those that involve concurrent use of the product by multiple renters (as in carpooling) or by the owner and the renter (as in some forms of home sharing). In such cases, more usage by the owner may not necessarily imply less usage by nonowners.

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Endnotes

[1] The term "sharing economy" has been used to refer to businesses that enable the foregoing of ownership in favor of "on-demand" access. In several cases, this involves a single entity that owns the physical assets (e.g., Zipcar for short-term car rentals). It also encompasses the peer-to-peer provisioning of services—e.g., Uber for transportation services, TaskRabbit for errands, and Postmates for small deliveries. For further discussion and additional examples, see Botsman and Rogers (2010), Malhotra and Van Alstyne (2014), Cusumano (2014), and Chase (2015).

[2] An article in the *New York Times* (2015) notes that the "average daytime speed of cars in Manhattan's business districts has fallen to just under 8 miles per hour this year, from about 9.15 miles per hour in 2009. City officials say that car services like Uber and Lyft are partly to blame. So Mayor Bill de Blasio is proposing to cap their growth." Note that, although the peer-to-peer product sharing we consider is different from the type of product sharing enabled by Uber (which requires the involvement of the owner as a service provider), the two share similarities in that they provide nonowners with access to a product without having to own it.

[3] A variety of pricing approaches are observed in practice. Some platforms allow owners to choose their own prices. Others (e.g., DriveMyCar) determine the price. There are also cases where the approach is hybrid, with owners determining a minimum acceptable price but allowing the platform to adjust it higher (e.g., Turo), or with the platform suggesting a price (e.g., JustShareIt) but allowing owners to deviate. From conversations the authors had with several industry executives, there appears to be a push toward platform pricing, with several platforms investing in the development of sophisticated pricing engines to support owners.

[4] Under a servicization model, the firm can exert costly effort to improve certain characteristics of the product such as its energy efficiency during use or its durability. This could lower the corresponding operating costs, which in turn could result in higher usage. The phenomenon of higher efficiency leading to more usage is commonly referred to as the *rebound effect*. See Greening et al. (2000) for an overview and references. In our setting, the introduction of collaborative consumption can lead, under some conditions, to higher ownership because of the rental income owners derive from ownership.

[5] Usage can be viewed as arising over multiple periods (over the lifetime of the product) with ξ being the usage per period. It is also possible to view usage as being random with an owner using the product for some of the periods and making the product available for rent over others. In that case, ξ can be used to indicate the probability that an owner (with type ξ) would use the product in a given period (and, correspondingly, $1-\xi$ to indicate the probability that an owner would not use the product). In other words, usage level in each period is either 1 or 0 with probability ξ and $1-\xi$, respectively. In turn, this implies that the *expected* usage level per period is ξ.

[6] If ξ corresponds to the usage level per period, the payoffs in (1) and (2) are also per period.

[7] In a multi-server loss queueing system, customers arrive over time to receive service from a set of identical servers. A customer who does not find an available server upon arrival leaves the system without getting service. A customer who finds one or more available servers proceeds to receive service from one of these servers. Service takes a specified amount of time. Upon completion of service, the corresponding server becomes available. Both the interarrival and service times can be stochastic. (See Cooper 1981 for additional details).

[8] For example, suppose the aggregate demand for renting per unit time is $D(\theta)=1{,}000$ hours and the aggregate supply for renting per unit time is $S(\theta)=2{,}000$ hours. If the average rental period is $m=5$ hours, then the arrival rate and the service capacity of the system are respectively $\lambda(\theta)=D(\theta)/m=200$ and $\mu(\theta)=S(\theta)/m=400$ requests per unit time.

[9] An alternative approach to constructing the matching functions α and β is to let $\alpha+\beta=t$, where $0<t<2$. Using (4), this leads to $\alpha=t(D/(S+D))$ and $\beta=t(S/(S+D))$. Higher values of t correspond to settings where matching friction is lower. Settings with $\alpha+\beta\neq 1$ lead to results that are qualitatively similar to those we obtain for $\alpha+\beta=1$. In particular, the results of Sections 3 and 4 regarding ownership and usage continue to hold. Moreover, we observe that an increase in t leaves ownership relatively unchanged (lower matching friction benefits both owners and renters) but increases usage (lower matching friction increases the likelihood of successful matches between owners and renters). In Online Appendix D, we describe another alternative *micro-model* for constructing the matching functions. As we discuss in the online appendix, the sum $\alpha+\beta$ does not necessarily have to add up to 1, with $\alpha+\beta<1$ ($\alpha+\beta>1$) corresponding to settings where the short-term fluctuations in supply and demand are high (low).

[10] An example of a not-for-profit platform is NeighborGoods, a peer-to-peer platform that facilitates the sharing of household goods. NeighborGoods allows owners to earn a rental fee but does not extract for itself a commission fee.

[11] This perhaps validates concerns expressed by the Singapore authorities that allowing peer-to-peer car sharing would increase car usage and road congestion and their initial decision to restrict peer-to-peer car rentals to evenings and weekends (Clifford Teo, CEO of iCarsClub, personal communication, 2015).

[12] It is possible to treat the reverse case. It is also possible to consider alternative assumptions, including the case where price and service level are endogenously determined through the dynamics of competition between the sharing platform and the service provider (we leave this as an area of future investigation).

[13] We can again show that, for any value of platform supply $S_p\geq 0$, an equilibrium (θ^*,α^*) exists and is unique for every feasible combination of parameter values. We can also show that θ^* and α^* are still increasing in c, γ, and d_o, but decreasing in p and d_r. In addition, θ^* increases while α^* decreases as S_p increases. The analysis is similar to that leading to Theorem 1.

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