

The Impact of Sharing Economy on Profitability, Environment and Innovation

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This dissertation is dedicated to my husband, Mahdi, who has been a constant source of support and encouragement during the challenges of graduate school and life. I am truly thankful for having you in my life. Without your support, this achievement would not be possible. This work is also dedicated to my parents, Mary and Mansoor, who have always loved me unconditionally.

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Abstract

The sharing economy has recently received much attention to determine whether it is economically viable and environmentally friendly. We study the effect of sharing economy on the economy, environment, and innovation.

First, we study the impact of the peer-to-peer sharing economy on the environment and manufacturer's profitability. There is an open debate on whether sharing economy or collaborative product consumption is environmentally friendly. The main arguments are as follows. First, the number of products produced may decrease under sharing economy, which has a positive impact on the environment. Second, access to the product may increase under sharing economy, which has a negative impact on the environment. Motivated by these arguments, we study the impact of peer-to-peer sharing economy business models on the economy and the environment. We investigate when the sharing economy business model results in a win-win strategy, where it can simultaneously increase a manufacturer's profits and decrease the environmental impact, as compared to other traditional consumption models such as pure sales and servicizing models. Our analytical results show that the sharing economy can lead to a win-win outcome with respect to both the manufacturer's profits and the environmental impact.

Second, we study the impact of ride-hailing on manufacturers' innovation in the car manufacturing industry. To measure innovation, we use the number of patents granted to each manufacturer in the period that goes from 2000 to 2020. The emergence of ride-hailing and its growth are measured based on the revenues of the two main

companies operating in this area, Uber and Lyft. Paradoxically, we find a strong positive impact of the ride-hailing growth on the number of manufacturers' patents, both as a direct effect and as mediated by the manufacturers' revenues. The rationale is that ride-hailing leads to a price increase in the car models that are adopted by drivers for ride-hailing. Therefore, manufacturers benefit from sharing economy and attain higher revenues as ride-hailing grows. The revenues increase, in turn, leads manufacturers to invest higher financial resources in research and development. Our results suggest that car manufacturing companies should support the practice of ride-hailing.

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Chapter 1

Introduction

Business models that provide access to the products rather than transform the ownership of products have become one of the most recent business model trends (Abhishek et al., 2021). One of these business models has been named *sharing economy*. Sharing economy refers to business models where consumers can share an underutilized resource through an online platform that matches supply and demand for the usage of that resource. Theoretically, there are two broad classes of sharing economy, based on the types of resources being shared (Tian and Jiang, 2018). In some cases, consumers may share their tangible assets or product through platforms for a short-term, such as Getaround for cars, VRBO for accommodation, 3D Hubs for 3D printers, and Spinlister for bikes. This example of sharing economy is referred to as “peer-to-peer product sharing” (Tian and Jiang, 2018; Benjaafar and Hu, 2020). In some other cases, consumers may share their time or provision services through platforms. A well known example of this type is ride-hailing platforms such as Uber and Lyft that match drivers with individual riders. This latter example of sharing economy is also referred to as “on-demand product sharing” (Benjaafar and Hu, 2020). The sharing economy business model differs from other recently popularized consumption models, such as servicizing, in that the product is shared from consumers to consumers (C2C) rather than from the firm to consumers (B2C). This business

model has experienced rapid growth due to technological advances. It is expected to be worth 335 billion dollars by 2025 (Pwc, 2015). Most of the transactions in sharing economy occurred in the following industries: Music and streaming video, transportation industry, hospitality industry, and fashion industry.

The sharing economy business model has received much attention from practitioners to determine its effect on social welfare, manufacturers, consumers, and the environment. As an example, Cachon et al. (2017) investigate the best mechanism of service charges and worker payments for sharing economy platforms. Bellos et al. (2017) consider the effect of car-sharing on an original equipment manufacturer (OEM) and its product line design. Jiang and Tian (2018) investigate the strategic and economic impact of sharing economy on consumers. Tian and Jiang (2018) study the impact of product sharing on the distribution channels.

Sharing economy can affect consumers' ownership preference and hence the manufacturers' profitability. On one hand, sharing economy may decrease ownership because consumers have renting options besides purchasing (*a cannibalization effect*). On the other hand, it can make the ownership more attractive because looking-forward consumers anticipate to obtain extra income by renting out their own product (*a value enhancement effect*). Specifically, for consumers with low usage rates, ownership may not be a possibility without the option of earning revenues from renting out their products.

Moreover, several companies have been recently involved in the product sharing market. As an example, General Motors partnered with RelayRides in 2013 (rebranded as Turo in 2015) to use its OnStar technology to facilitate the participation of GM customers in the product sharing market. More recently, Ford company teamed up with Google to launch its product sharing platform. Toyota company has invested in Getaround to expand its market in North America. The company considers this as a way to decrease the ownership costs for its products. They provide an option to the car owners to pay their lease directly from the money they obtain by renting out their

car on Getaround¹. This illustrates that although manufacturers have been actively reacting to the product sharing consumption trend, how to better adjust to it is far from obvious for manufacturers. It remains largely unclear under what conditions product sharing is helpful for the manufacturer.

Also, sharing economy business models have received much attention from practitioners to determine whether they are environmentally friendly, especially as compared to usual consumption models. Sharing economy business model has both pros and cons from an environmental perspective. For example, in the presence of sharing economy, a portion of the consumers decides to rent the product rather than purchase it, and they pay-per-use to use the product. This pay-per-use reduces the usage of the products compared to when consumers own the product. However, sharing economy increases product accessibility, because under this business model consumers have the option to access the product by renting it. Therefore, the usage of the product may increase by increasing its accessibility of the product. Moreover, under sharing economy, the production quantity may reduce which is good for the environment. On the other hand, since the production quantity reduces under sharing economy, the manufacturer may have an incentive to reduce product durability to compensate for the lower production quantity.

In particular, peer-to-peer product sharing raises several unanswered and important questions:

- How does sharing economy affect manufacturers' profitability and the environment?
- How should a manufacturer choose its product efficiency and retail price in sharing economy?
- How does sharing economy in terms of profitability and environmental impact to other consumption models, such as the pure sales model and servicizing?

¹“Getaround Announces Carsharing Partnership with Toyota”, <https://www.getaround.com/about-press-releases/getaround-announces-carsharing-partnership-with-toyota>, accessed (8 April 2022)

Motivated by this trend, in Chapter 2, we develop a game-theoretical model to investigate the effect of peer-to-peer product sharing on manufacturer’s prices, product efficiency, sales, profitability, and the environment. Also, we study when peer-to-peer product sharing can be a win-win strategy that is, it both increases the manufacturer’s profits and decreases the environmental impact, as compared with other consumption models such as pure sales and servicizing business models. Our analysis shows that peer-to-peer product sharing can be a win-win strategy, in that it outperforms both pure sales and servicizing business models. The dominance of sharing economy is contingent upon product type, heterogeneity in product needs among consumers, and the level of pooling of product usage needs. Our results have important managerial implications for both manufacturers and policy-makers.

In Chapter 3, we study the effect of on-demand product sharing on manufacturers’ profitability and innovation incentives. In particular, we conduct empirical research to investigate the effect of the emergence and growth of on-demand product sharing in the transportation industry on manufacturers’ profitability and innovation in the car manufacturing industry. The ride-hailing platforms such as Uber and Lyft implement on-demand product sharing in the transportation industry. These platforms match people who need a ride (or riders) with drivers who are willing to provide it using their vehicles. The ride-hailing business model has experienced rapid growth due to technological advances. Uber and Lyft were worth 51.3 billion dollars in 2017, and it is expected to grow by over 400% in the next five years (Stasha, 2022). In recent years, several car manufacturers companies have been involved in ride-hailing platforms. For example, General Motors invest 500 million dollars in Lyft in 2016 and Volkswagen invest 300 million dollars in Gett (an Israeli ride-hailing platform) in 2016 (Kosoff, 2016). However, the relationship between the emergence and growth of ride-hailing platforms on car manufacturing companies’ profitability and innovation is not clear.

Because ride-hailing platforms can lead to a “cannibalization effect” as well as a “value enhancement effect” on product sales (Jiang and Tian, 2018), the implication

of ride-hailing platforms on manufacturers' profitability is not clear. Also, under the presence of a ride-hailing platform, the manufacturer may increase the sales price.

Also, the implication of the ride-hailing platform on the innovation of auto industry is not clear. The growth of ride-hailing platforms may encourage auto manufacturers to produce more efficient products (in terms of speed, fuel efficiency, etc.) (Jiang and Tian, 2018; Bellos et al., 2017). Also, it may encourage the manufacturers to be less innovative, since ride-hailing users (both drivers and riders) demand more reliable vehicles, but they are indifferent to the features.

As ride-hailing is exponentially growing, it is vital to understand its impacts on the industry. In Chapter 3, we assess the impact of ride-hailing platforms entry and growth on the profitability and innovation of companies in the auto industry in the United States.

To find this effect, our study empirically addresses two interrelated research questions. First, what is the impact of ride-hailing growth on manufacturers' profitability? Second, what is the impact of ride-hailing growth on innovation? Based on the existing literature, we use both research and development expenditures (R&D) which is an input for innovation, and patent data which is output for innovation, as an indicator to capture the manufacturers' innovation (Zhao, 2009). To empirically test the hypothesized relationship, we collected data from several databases to control other factors at the economic level, industry level, and manufacturer level.

We find a strong positive impact of ride-hailing growth on the manufacturers' innovations, both as a direct effect and as mediated by the manufacturers' revenues. The rationale is that sharing economy leads to a price increase in the cars models that are adopted by drivers for ride-hailing. Therefore, manufacturers benefit from sharing economy and attain higher revenues as sharing economy grows. The revenues increase leading manufacturers to invest higher financial resources in research and development. Our results suggest that the car manufacturers industry should support the practice of ride-hailing.

Chapter 2

The Economic and Environmental Impact of Sharing Economy Business Models

2.1 Introduction

Sharing economy refers to business models where consumers can share an underutilized resource through an online platform that matches supply and demand for the usage of that resource. In some cases, consumers may share their time or provision services through platforms, such as Uber and Lyft for transportation services or TaskRabbit for household tasks. In some other cases, consumers may share their tangible asset or product through platforms, such as Getaround for cars, VRBO for accommodation, 3D Hubs for 3D printers, and Spinlister for bikes. The latter example of sharing economy is also referred to as “peer-to-peer product sharing” (Tian and Jiang, 2018; Benjaafar and Hu, 2020), and is the focus of this work. This business model differs from other recently popularized consumption models, such as servicizing, in that the product is shared from consumers to consumers (C2C) rather than from the manufacturer to consumers (B2C).

To illustrate, consider the company Getaround. This peer-to-peer carsharing service requires owners to list their car and install the GetaroundConnect device. Thanks to this device, owners can remotely unlock their vehicle through a smartphone app, whereas drivers use the same app to get access to the car. After finishing their trip, the drivers pay the rental on an hourly basis to the online platform. Getaround keeps 40% of the rental fee, whereas the remaining 60% of it is received by the car owners. The company had five million users and nearly 20,000 connected cars by 2019. Getaround operates in most major cities in the U.S., such as Boston, Chicago, San Francisco, New Jersey, Seattle, Philadelphia, Miami, Atlanta, etc., and is quickly expanding its business in Europe.¹

Sharing economy business models, such as Getaround, have received much attention from practitioners to determine whether they are economically viable and environmentally friendly, especially as compared to usual consumption models (Jiang and Tian, 2018; Benjaafar et al., 2019; Bellos et al., 2017).

For instance, when the product is shared among consumers, there may be a lower number of purchases as compared to a situation where the product is not shared. Hence, the number of products produced should decrease under sharing economy, possibly leading to lower profits but “greener” environment. Further, the consumers who rent the product typically pay a per-usage price, which may lower the product usage as compared to a situation where the product is purchased (Agrawal and Bellos, 2017). Lower product usage, in turn, would positively affect the environment. Finally, the consumers who purchase the product envisage a higher usage of it when their product is shared than when it is used exclusively by them (Bellos et al., 2017). As a consequence, these consumers value higher product efficiency, and thus the manufacturer may have an incentive to increase efficiency for higher price, resulting in both higher profits and lower consumption of energy..

¹“ABOUT GETAROUND”. <https://www.getaround.com>. (accessed 8 April 2022).

However, for each of the arguments above there is a possible counter-argument. For example, sharing economy may make product ownership more attractive (Benjaafar et al., 2019), because it provides the owner with the opportunity to gain extra income through the rental of his product. As a consequence, the number of product purchases may increase, possibly leading to higher profits but a deteriorated environment. Further, product sharing can substantially augment consumers' access to the product, and thus its usage. Finally, because the products are shared the manufacturer may fear a drop in sales, and thus have an incentive to produce less efficient products to counteract such sales reduction.

Given these contrasting arguments, peer-to-peer product sharing raises several unanswered and important questions. How does peer-to-peer product sharing affect manufacturer's profitability and the environment? How should a manufacturer choose its product efficiency and retail price under sharing economy? How does peer-to-peer product sharing compare in terms of profitability and environmental impact to other consumption models, such as pure sales model and servicizing ? In particular, are there instances where peer-to-peer product sharing outperforms these other models with respect to both the manufacturer's profitability and the environment? To answer these questions, we developed a game theoretical model of peer-to-peer product sharing involving three players: the manufacturer, the sharing platform and the consumers. The manufacturer produces a single product and must decide on price and efficiency before selling the product to the consumers. The platform enables product sharing and must decide on the share of the fee that goes to the consumers who make their product available for rental. Consumers are heterogeneous in their product usage needs and have to decide how to satisfy these needs: by purchasing and using the product or by renting it from other consumers through the platform. In other words, under peer-to-peer product sharing consumers can be either product owners or renters (except for the trivial case, where they remain inactive). Using this model, we investigate profitability and environmental impact of the sharing economy business model, and compare it to other common consumption models, i.e., pure sales,

pure servicizing, and hybrid servicizing, where product sharing is not available and consumers can purchase from the manufacturer only the product, only the product use and either the product or its use, respectively.

In particular, following the extant literature, we measure the environmental impact based on the two different phases of the product life cycle: production and usage.

Our research provides the following results and insights. First, we show that in a setting where the manufacturer only sells its product and there exists a sharing economy platform, product sharing arises as a unique equilibrium when either the consumers are sufficiently heterogeneous in their product usage need or the portions of consumers with different usage needs are sufficiently similar. The first condition is straightforward as product sharing requires that some consumers self-select into owners and others into renters, and this is only possible if consumers are sufficiently heterogeneous in their usage needs. As for the second condition, a low number of consumers with high product usage need would result into a limited number of product owners, and thus limited sales for the manufacturer. On the contrary, a high number of these consumers would result into an increased competition among owners renting out their product, and thus a reduction of the associated margins. As a consequence, the number of owners and renters must be similar to let sharing economy emerge as a unique equilibrium. Interestingly, we also show that under similar but less stringent conditions sharing economy can still emerge as one of multiple equilibria.

Second, we compare the manufacturer's choice of product efficiency under sharing economy with that under other consumption models (where product sharing is not available). Note that product efficiency reduces the consumers' product operating cost, but it comes at a (production) cost to the manufacturer. First, we show that product efficiency is always higher under sharing economy than under pure sales model. The rationale is that product usage, and thus the operating cost, is higher for consumers purchasing, using on their own and then sharing their product than for those only purchasing and using it. Therefore, higher values of efficiency, leading to

lower operating costs, are more valuable under sharing economy than under a pure sales model. The manufacturer, then, finds it optimal to offer higher efficiency while charging higher price for the product sold under the former than under the latter model. Second, we show that product efficiency is higher under sharing economy than under servicing if and only if the pooling effect is sufficiently low.

In fact, low pooling implies that the manufacturer must produce a high number of products to meet its customers' usage needs through servicing. As a consequence, the production cost increases and thus the manufacturer has an incentive to decrease product efficiency.

Third, we find the conditions under which sharing economy is more profitable than other popular consumption models. In particular, sharing economy is more profitable than the pure sales model under similar, yet more stringent, conditions than those under which sharing economy arises as a unique equilibrium. In particular, a lower level of product owners is needed for sharing economy to outperform pure sales. The reason for a lower level of product owner is that when the manufacturer sells the product to only consumers with high usage needs then it will set a higher price for the products than the one when manufacturer sells the product to consumers with low usage needs as well as high usage needs. Therefore, sharing economy can only occurs for a more limited level of product owner. Further, sharing economy outperforms both pure sales and pure and hybrid servicing when, in addition to the previous conditions, it also holds that either the level of pooling and the marginal production cost are sufficiently low.

In fact, as we previously discussed under servicing these conditions leads the manufacturer to decrease efficiency because of the high production cost incurred. A low efficiency in turn results into a high operating cost, which reduces the product aggregate usage and thus the manufacturer's revenues.

Forth, we explicitly characterized the conditions under which sharing economy is environmentally superior to pure sales, hybrid and pure servicing business models. First, we show that sharing economy is environmentally superior to pure

sales model only if the owners' product usage needs are not too different from the non owners' ones. In fact, under this condition and absent the peer-to-peer product sharing, all consumers would purchase the product. The ensuing high number of products deteriorates the environment. Second, we show that sharing economy is environmentally superior to hybrid servicizing only for the product whose environmental impact is mainly determined by the production phase. The reasoning is that sharing economy has an advantage over hybrid servicizing during the production phase, since it requires to produce the products only for the consumers who have high product usage need. Therefore, for all product categories where the production phase has a sufficiently higher environmental impact than the usage phase sharing economy will be environmental superior to hybrid servicizing. However, when compared to pure servicizing, sharing economy is environmentally superior for the products whose environmental impact is mainly determined by the production phase only if there is a weak pooling effect. Under weak pooling, the manufacturer requires to produce a high number of products to meet consumers' usage needs. Therefore, sharing economy has an advantage over pure servicizing under production phase if the pooling effect is sufficiently weak.

Finally, we combine the comparison of sharing economy with the other consumption models, and find conditions under which sharing economy is a win-win, in that it outperforms these models from both an economic and environmental perspective. We find that when the portions of consumers with different usage needs are sufficiently similar, sharing economy leads to a win-win strategy as long as the pooling effect and the heterogeneity in product usage needs are sufficiently low.

2.2 Literature Review

A stream of literature in sustainable operations studies the impact of various business models on profits and environment. For example, [Agrawal et al. \(2012\)](#) study when leasing is more profitable and environmentally superior to pure sales. They show that

leasing can lead to a win-win strategy for products that have a higher use impact and low durability. In our paper, we focus on peer-to-peer product sharing which differs from leasing in two important aspects: (i) the owner of the shared product is a consumer as opposed to the manufacturer in leasing, and (ii) the payment for the shared product is variable, as it depends on usage, as opposed to fixed cost per product in leasing. Another consumption model that has been studied in previous works is servicizing. [Agrawal and Bellos \(2017\)](#) and [Örsdemir et al. \(2019\)](#) investigate the conditions under which servicizing models are both more profitable and environmentally superior than a pure sales model. [Agrawal and Bellos \(2017\)](#) show that the environmental impact of servicizing depends on pay-per-usage price and degree of pooling. [Örsdemir et al. \(2019\)](#) show that servicizing can be a win-win strategy and it depends on the product type, the efficiency of the product, and the valuation gap between the consumer segments. We contribute to this literature by investigating when peer-to-peer sharing economy can be a win-win strategy. Peer-to-peer product sharing is different from servicizing with respect to product ownership. Under product sharing, the product owner is a consumer, who may decide to rent out his product to non-owners through an online platform. Under servicizing, the product owner is the manufacturer, which by itself rents out its product to consumers.

Several studies investigate various environmental aspects of the business models. For firms operating under a pure sales model, previous literature has studied sustainability strategies such as extended producer responsibility ([Plambeck and Wang, 2009](#); [Atasu and Subramanian, 2012](#)), competition in product recovery ([Örsdemir et al., 2014](#)), and manipulation of the emission tax rate to drive investments in clean production technology ([Drake et al., 2016](#)). The leasing business model has a main difference with pure sales, that is, the product is owned by the firm while the consumer is leasing the product. [Agrawal et al. \(2012\)](#) adopt a life-cycle environmental impact perspective and analytically investigate whether leasing can be both more profitable and have a lower total environmental impact than a pure sales model. [Lim et al. \(2015\)](#) show that a business model that requires consumers to lease

electric vehicles batteries may lead to a greater level of adoption of electric vehicles, and thus greater emissions savings especially when the level of resale anxiety is high. Both the models of pure sales and leasing do not involve the sharing of the product from its owner to other consumers, which is the main aspect of our study.

There is a growing attention on the business model of sharing economy, but the joint study of economic and environmental impact has never been addressed. [Cullen and Farronato \(2021\)](#) develop a model for peer-to-peer labor marketplaces. They find that supply is highly elastic, meaning that when demand doubles, sellers perform almost twice as many tasks without significant impact on price. [Bellos et al. \(2017\)](#) consider the effect of car sharing on product line design. The authors study the best strategy for the type of vehicles that should be provided by auto manufacturers that have recently introduced car sharing program such as Daimler and BMW. [Jiang and Tian \(2018\)](#) show that, while demand for ownership decreases, product prices increase because consumers who buy the product anticipate the added income the product offers when renting its services to others. The authors find that sharing of high marginal cost products is a win-win situation for both manufacturers and consumers, whereas sharing of low marginal cost products can be a lose-lose situation. [Tian and Jiang \(2018\)](#) extend their model to consider the effect of product sharing on the distribution channel. They develop a two-period model in which individuals first decide whether to purchase the product. Then, in each period, owners decide to use the product themselves or rent it out. They show that peer-to-peer product sharing leading to an increase in the manufacturer's production, especially when the upstream manufacturer's capacity cost is high. Also, they result implies that product sharing can be lose-lose, lose-win, or win-win for the upstream manufacturer and the downstream retailer. They don't consider the effect of online platform, as we do in the product sharing market. The online platform has an intermediary role, and reduces market friction ([Benjaafar and Hu, 2020](#)). [Blaettchen et al. \(2018\)](#) investigate the interaction of peer-to-peer product sharing market and heavy equipment manufacturer. They consider the case where the manufacturer establish

a sharing platform. They find the presence of sharing platform is harmful for the manufacturer if the shared equipment has high wear and tear cost. [Benjaafar et al. \(2019\)](#) describe an equilibrium model for product sharing. They assume consumers are heterogeneous in their product usage and that usage is exogenous and they focus on the decision of the platform. In contrast, we determine the optimal usage by maximizing consumers' net utility. Also, they don't consider the manufacturer roles, as we do, in sharing market. [Abhishek et al. \(2021\)](#) examine different business model of the manufacturer such as pure sales, with rental in addition, with its own peer-to-peer rental platform, and with a mixed structure in which the manufacturer competes against another peer-to-peer rental platform. They find that the consumer heterogeneity in usage rates play an important role in business outcome. if the consumers are homogeneous in their usage, then both consumers and manufacturer suffer from the presence of the peer-to-peer product sharing market. However, if the consumers are heterogeneous in their usage, then both consumers and manufacturer obtain benefit from the presence of peer-to-peer product sharing market. However, they do not consider the product efficiency in their model as we do.

Overall, in the context of peer-to-peer product sharing this is the first paper, to the best of our knowledge, that analyzes the effect of product sharing economy on the manufacturer's profitability and the environment.

2.3 Model

We consider a peer-to-peer product sharing, where a monopolist manufacturer produces a single product and sells it to the consumers. Consumers, in turn, can either decide to purchase the product from the manufacturer or rent it from other consumers through a sharing platform. In the following, we specify the model of consumers, platform, and manufacturer. Table [2.1](#) summarizes the main notation.

Table 2.1: Main notation

Parameters	
θ_i	product usage need for segment i of consumers, $i = \{H, L\}$
α	portion of θ_H reflecting the product usage need for the low segment of consumers, so that $\theta_L = \alpha\theta_H$
M	number of consumers
β	portion of the M consumers who belong to the high-end segment
k	operating cost per unit of product efficiency and usage
c	production cost per unit of product efficiency and per unit of product
Market-Clearing Variable	
w	market-clearing fee paid by renters to the platform
Decision Variables	
τ	product usage by consumers
φ	portion of w that accrues to owners when they rent out their product
e	product efficiency
p	product sale price

2.3.1 Consumers

Consumers are heterogeneous in terms of their usage need for the manufacturer product. There are two consumer segments which are characterized by θ_i , $i \in \{H, L\}$, where θ_H and θ_L represent the usage need of high- and low-end segments of consumers (or high- and low-type consumers), respectively. We assume $\theta_H = 1$, whereas $\theta_L = \alpha$, $\alpha \in (0, 1)$. The mass of potential consumers is M and $\beta \in (0, 1)$ represents the fraction of θ_H consumers.

The utility a consumer derives from a product usage deteriorates after each use. The gross utility of a consumer of segment i from product usage τ is given by $V_i(\tau) = \theta_i \tau - \frac{\tau^2}{2}$, which is concave increasing in τ . Therefore, a consumer derives greater utility from higher usage, but with decreasing returns. The expression of this utility is similar to the one used in [Agrawal and Bellos \(2017\)](#) and [Örsdemir et al. \(2019\)](#).

Consumers can fulfill their need for product usage in two ways: they can 1) purchase and then use their own product, or 2) rent the product from other consumers through the sharing platform. Hereupon, we will refer to consumers in case 1) as *owners*, whereas to those in case 2) as *renters* and will use the superscript $j = \{o, r\}$ to denote these two types of consumers. Owners will pay the sale price, p , to the manufacturer, whereas renters will pay a rental fee, w , to the platform. Owners who rent out their product will retain a portion, φ , of the rental fee w . For simplicity, we normalize the cost of renting out the product, such as the cost of delivering and picking up the product, or the accelerated product maintenance cost due to moral hazard of the renter, etc., to zero ([Jiang and Tian, 2018](#)).²

Finally, there is a cost of operating the product. This cost includes both the maintenance cost to keep the product operational and the cost of using the product (e.g., paying the fuel for using a car). Since a more efficient product requires less maintenance and less energy we assume that the operating cost is decreasing in

²The assumption of normalizing the cost of renting out the product to zero is not restrictive. In fact, a sufficiently high value for this cost would just result in the segment of owners not renting out their product; as a consequence, sharing economy will not arise. However, a sufficiently low value for it would provide the same qualitative results as in the case of cost normalized to zero.

the product efficiency chosen by the manufacturer. For tractability, we assume a linear form of the operating cost in the efficiency and model it as $k(1 - e)\tau$, where k represents the operating cost per unit of usage and e is the product efficiency.

2.3.2 Platform

The platform allows that product owners share their product with the renters. In equilibrium, we assume that supply and demand for product usage will be equal. Therefore, the per use fee, w , is a market-clearing fee that matches supply with demand. The platform selects the variable φ to distribute the fee w between owners who rent their product out and the platform itself. Specifically, each consumer needs to pay w to rent the product from the platform, and a consumer who rents out his product will receive a payment φw while the platform keeps $(1 - \varphi)w$ as its service fee.

2.3.3 Manufacturer

The manufacturer selects the product efficiency, denoted by $e \in (0, 1)$. A higher value of e implies a more efficient product (Bellos et al., 2017). To focus on interior values of the efficiency, we make the following assumption.

Assumption 1. $k < \min\{1, 2c\}$.³

The manufacturer's per unit production cost is given by ce^2 . Note that ce^2 is increasing convex in efficiency as manufacturing a more efficient product may require higher-quality and thus more costly materials. As we already mentioned, the manufacturer's choice of product efficiency influences the consumer's utility from product usage, $U_i(\tau)$, by affecting the consumer's operating cost.

The manufacturer also selects the product selling price, p . A low price may induce all consumers to purchase the product, whereas a high price may boost the sharing

³Assumption 1 reduces the number of cases to analyze and ensures tractability.

market as many consumers would not eventually have a high enough need for the product to justify its purchase. Depending on the price, the platform may adjust the portion of its service fee, φ . The manufacturer, then, maximizes its profits anticipating the possible reactions of platform and consumers.

The timing of events is depicted in Figure 2.1. As one can notice from this figure, there are three players in our model which results in solving a cascade of three optimization problems. In this sense, we have tried at best to keep the model sufficiently meaningful for the research we conduct while also ensuring tractability. In particular, consumers make two decisions, the first at time 2, where they decide whether to purchase the manufacturer's product and the second at time 5, where they decide how to satisfy their product usage need, i.e., whether to use their product (in case they are owners) or to use a rented product (in case they are renters).

2.3.4 Consumers, Platform and manufacturer Decisions

Each consumer decides whether to purchase and use his own product or to rent it from another consumer. The consumer who purchases the product, i.e., the product owner, can make additional money from renting it out as long as there is a platform that enables product sharing. We use the subscript $z \in \{s, n\}$ to distinguish between the cases where the owner shares (subscript s) or does not share (subscript n) his product. Further, the consumers' net utility, $U_{iz}^j(\tau)$, also depends on whether consumers are owners or renters ($j \in \{o, r\}$) and whether they belong to the high- or low-segment, ($i \in \{H, L\}$):

$$U_{iz}^o(\tau) = \begin{cases} V_i(\tau) - p + (\varphi w)(1 - \tau) - k(1 - e)\tau, & \text{if } z = s \\ V_i(\tau) - p - k(1 - e)\tau, & \text{if } z = n \end{cases}, \text{ and} \quad (2.1)$$

$$U_{iz}^r(\tau) = \begin{cases} V_i(\tau) - w\tau - k(1 - e)\tau, & \text{if } z = s \\ 0, & \text{if } z = n \end{cases}. \quad (2.2)$$

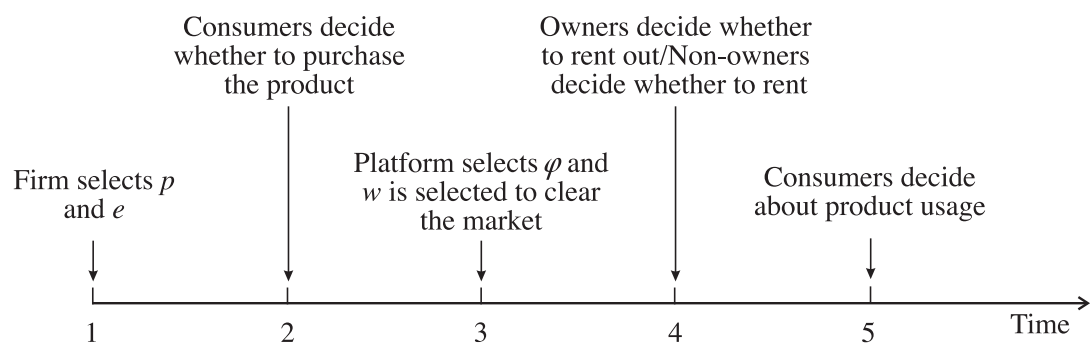


Figure 2.1: Timing of events

Notice that in expression (2.1) it is assumed that each product has a maximum usage of 1. Put differently, the owners use their product according to their needs at a level τ ; if the platform entered the market, the consumers will rent out their product for the remaining usage, $(1 - \tau)$. In expression (2.2), $U_{in}^r = 0$ because in the absence of sharing economy, consumers who did not purchase the product, i.e., renters, will remain inactive. The sharing economy is active if all the following conditions are satisfied: (i) only one consumer segment purchases the product, (ii), the platform enters the market, (iii) the product owners prefer using and renting out the product rather than just using it, and (iv) the product renters prefer renting the product rather than remaining inactive.

We now proceed with the formal analysis of the game between consumers, platform and manufacturer, considering the timing of events represented in Figure 2.1. By backward induction, at time 5, a consumer of segment θ_i maximizes his utility $U_{iz}^j(\tau)$, and thus selects the optimal usage of the product, τ_{iz}^{j*} , as long as $U_{iz}^j(\tau_{iz}^{j*}) \geq 0$. Mathematically,

$$\begin{aligned} \tau_{iz}^{j*} &= \underset{\tau \geq 0}{argmax} U_{iz}^j(\tau) \\ s.t. \quad & U_{iz}^j(\tau) \geq 0. \end{aligned} \tag{2.3}$$

Next, at time 4 owners decide whether to rent out their assets and non-owners decide whether to rent or stay inactive. Then, at time 3, if there are both owners and renters, the platform enters the market and has to select the variable φ knowing that it will accrue the portion $(1 - \varphi)$ of the rental fee w . As mentioned above, w is chosen to clear the market, that is:

$$w^* = w \mid M^o(1 - \tau_{is}^{o*}) = M^r \tau_{-is}^{r*}, \tag{2.4}$$

where M^o and M^r are the number of product owners and renters, respectively, and $-i$ denotes the consumer type different from i , with $i \in \{H, L\}$. For instance, if only the consumers of the high-segment purchased the product, then $M^o = \beta M$, whereas

$M^r = (1 - \beta)M$. To select φ , the platform solves the following optimization problem, which includes the constraints that a sharing economy is active:

$$\begin{aligned}
\max_{\varphi} \quad & \Pi_{pl} = (1 - \varphi)M^o(1 - \tau_{is}^{o*})w^* \\
\text{s.t.} \quad & U_{is}^o(\tau_{is}^{o*}, w^*, \varphi) \geq U_{in}^o(\tau_{in}^{o*}) \\
& U_{-is}^r(\tau_{-is}^{r*}, w^*) \geq 0 \\
& 0 \leq \varphi \leq 1,
\end{aligned} \tag{2.5}$$

where w^* is given by (2.4). The first constraint in problem (2.5) requires that the segment i who purchased the product (i.e., the segment of owners) prefers to share rather than not to share the product. The second constraint, instead, requires that the segment $-i$, who did not purchase the product (i.e., the segment of renters), prefers renting the product rather than remaining inactive. In other words, the constraints in (2.5) make sure that only one type of consumers purchased the product; otherwise, the platform would not have any incentive to enter into the market. By solving (2.5), we determine the conditions under which the platform enters the market, and thus, sharing economy becomes active. The next lemma formalizes the results.

Lemma 1. *When only one segment, θ_i , purchases the product, the platform enters the market to enable product sharing according to the following conditions:*

1. if $i = H$, when $e \geq 1 - \frac{\alpha(1-\beta)}{2k}$,
2. if $i = L$, when $e \geq 1 - \frac{\alpha(2-\beta)-2(1-\beta)}{2k}$.

Lemma 1 states that the platform enters the market to enable product sharing as long as the product efficiency chosen by the manufacturer is sufficiently high. The intuition for this result is straightforward. In fact, if the product is shared, its usage increases to the maximum level of 1. Therefore, product sharing will be only feasible when the operating cost is sufficiently low. This condition, in turn, requires product efficiency to be sufficiently high.

Intuitively, one would think that, all else equal, the efficiency requirement to enable product sharing should be stricter for the low than for the high segment, as the former segment accrues lower utility from product usage than the latter ($V_L^o(\tau) < V_H^o(\tau)$). However, this is not always the case. By comparing the efficiency requirements of Lemma 1, one can notice that the previous intuition holds as long as either a) $\beta \leq \frac{1}{2}$, or b) $\alpha < 2(1 - \beta)$. In particular, Condition a) states that there are more low- than high-segment users, which means the low segment users would face high competition from renting out the product, which would boost the rental fee, and thus erode the benefit of renting the product. In this case, then low-segment consumers would rent the product only if product efficiency is sufficiently high. Condition b), instead, states that when there is not much competition in product sharing, yet low-segment users have low product usage need (i.e., α is low), and thus they need a high product efficiency to compensate for that.

At time 2, anticipating that the platform may enter the market as per Lemma 1, each segment of consumers decides whether to purchase the manufacturer product. Apart from the trivial case where no segment makes a purchase, there are three possible cases:

- 1) **Only the high segment purchases the product;**
- 2) **Both high and low segments purchase the product;**
- 3) **Only the low segment purchases the product.**

Clearly, the product can be shared only in cases 1) and 3), i.e., where only one segment purchases the product. In particular, if one of these cases holds we know that the product will be certainly shared when the condition on efficiency for segment i is satisfied as per Lemma 1.

Finally, at time 1 of the game, the manufacturer selects the case (among the three above) that, at optimal efficiency and price, maximizes its profits. Mathematically,

the manufacturer solves the following problem:

$$\max_{\{case1),2),3)\}} \left\{ \begin{array}{ll} \max_{p,e} & \Pi_f^i = M_o[p - ce^2] \\ s.t. & \text{case } i) \text{ holds,} \\ & i = 1, 2, 3 \end{array} \right\}. \quad (2.6)$$

However, we next show that case 3) is impossible, which restricts the manufacturer to choose between cases 1) and 2).

Lemma 2. *If low-type consumers purchase the product, so do high-type consumers.*

Lemma 2 suggests that the only possible case of sharing economy is when high segment consumers buy and rent out the product to low segment consumers. This is intuitive as high segment users have higher product usage need than the low segment ones. As a consequence, if the latter consumers find it optimal to purchase the product, so do the former ones. Notice that this result does not contradict the findings of Lemma 1, but actually complements them. Lemma 1, in fact, stated that in case only one segment of consumers had purchased the product then the platform would enter into the market and enable the product sharing only if the manufacturer had chosen a sufficiently high efficiency level. Lemma 2, however, establishes that it is never possible that only the low segment consumers purchase the product; thus, the only relevant result of Lemma 1 is the one for the high-segment consumers, i.e., $i = H$.

Hereupon, we refer to the two only possible cases of product purchase, case 1) and 2), as to “sharing” and “buy-buy”, respectively. Correspondingly, we will use the superscript “*sh*” for sharing and “*bb*” for buy-buy. It is instructive at this point to explicit the manufacturer’s optimization problem in (2.6) for each of the two cases,

sharing and buy-buy. Under sharing, the manufacturer solves:

$$\begin{aligned}
\max_{p,e} \quad & \Pi^{sh} = \beta M(p - ce^2) \\
s.t. \quad & U_{Hs}^o(\tau_{Hs}^{o*}, w^*) \geq U_{Hs}^r(\tau_{Hs}^{r*}, w^*) \\
& U_{Ls}^r(\tau_{Ls}^{r*}, w^*) \geq U_{Ls}^o(\tau_{Ls}^{o*}, w^*) \\
& 1 - \frac{\alpha(1-\beta)}{2k} \leq e < 1,
\end{aligned} \tag{2.7}$$

where the two first inequalities are the two incentive-compatibility (IC) constraints: The first requires that the high-type consumers prefer purchasing than renting the product, whereas the second requires the opposite preference for the low-type consumers. The third constraint in (2.7) comes from (inequality 1 in) Lemma 1 and the condition $e \in (0, 1)$.

There are two observations to make at this point. The first is that the incentive-compatibility constraints in (2.7) result into a range of possible values for the price p , and can be expressed as $p \in [p^{lb}, p^{ub}]$. The second is that under sharing the manufacturer will always choose the price at its upper bound, i.e., $p^{*sh} = p^{ub}$, as the objective function is linear increasing in price.

Under buy-buy, the manufacturer solves:

$$\begin{aligned}
\max_{p,e} \quad & \Pi^{bb} = M(p - ce^2) \\
s.t. \quad & U_{Hn}^{o*}(\tau_{Hn}^{o*}) \geq 0 \\
& U_{Ln}^{o*}(\tau_{Ln}^{o*}) \geq 0 \\
& 0 < e < 1,
\end{aligned} \tag{2.8}$$

where the first two inequalities are the individual rationality (IR) constraints ensuring that either of the two segments attains a non negative utility. The solution to (2.8) is such that the second constraint is binding, i.e., the manufacturer extracts all the surplus from the low-segment consumers.

By selecting price and efficiency the manufacturer decides whether to enable product sharing. In particular, either product sharing or buy-buy can emerge as the unique equilibrium according to the following sufficient conditions:

- **sharing:** $p^{*bb} \leq p^{*sh} = p^{ub}$ and $\Pi^{*bb} < \Pi^{*sh}$,
- **buy-buy:** $p^{*bb} < p^{lb}$ and $\Pi^{*bb} > \Pi^{*sh}$, or $p^{*bb} > p^{*sh} = p^{ub}$.

Sharing will be the manufacturer's choice only if the manufacturer can charge a higher selling price under sharing than under buy-buy. In fact, this is the necessary condition that makes the former option more profitable than the latter one, as product sharing already has the disadvantage of a lower volume of sales as opposed to buy-buy (i.e., M versus βM , respectively). On the contrary, the manufacturer will choose buy-buy when the related selling price falls outside the incentive compatible range of prices, i.e., $p^{*bb} \notin [p^{lb}, p^{ub}]$, and the manufacturer's profits are higher under this option (condition that is automatically satisfied when $p^{*bb} > p^{*sh}$). On purpose, we did not include the case where the manufacturer makes higher profit under buy-buy than under sharing, but the price under buy-buy falls into the incentive-compatible range of prices, i.e., $\Pi^{*bb} > \Pi^{*sh}$ and $p^{*bb} \in [p^{lb}, p^{ub}]$. In this case, in fact, we will show that there are multiple equilibria. The next result, instead, characterizes the the sharing economy as the unique equilibrium.

Proposition 1. *Product sharing arises as the unique equilibrium if and only if one of the following conditions holds:*

1. $\alpha \leq k$,
2. $\beta \in [\beta_{R_1}, \min\{\beta_{R_2}, 1\}]$, where β_{R_1}, β_{R_2} are roots of $\Pi^{*sh} = \Pi^{*bb}$ (details are in the Appendix).

Proposition 1 states that sharing economy emerges as the unique equilibrium under two scenarios. The first scenario occurs when the heterogeneity in product

need between the two segments of consumers is sufficiently high (i.e., $\alpha \leq k$).⁴ This heterogeneity guarantees that only the high segment consumers are willing to purchase the manufacturer product, whereas the low segment consumers, having a distinctly lower usage need, are satisfied with just renting the product. This result is intuitive as the manufacturer would always be better off to sell its product to both segments of consumers, were they too similar in their usage needs. To activate product sharing, then, a sufficient difference in product usage need is required.

The second scenario occurs when consumers are not so heterogeneous in their product usage need (i.e., $\alpha > k$), but the number of high-type consumers, β , is intermediate, that is, neither too high nor too low. The intuition is as follows. If β is too low, then sharing economy will have the disadvantage of a too low volume of sales. Even though the selling price is greater under sharing economy than under buy-buy, the size of the market is too narrow for the manufacturer to let sharing economy emerge. On the contrary, if β is too high, then the competition among product owners in renting out their product results into a drop of the rental fee. The manufacturer, then, will have a lower surplus to extract from the product owners, and thus will not be able to charge a high selling price. As a consequence, sharing economy will emerge as the unique equilibrium when the number of high-type consumers is neither too high nor too low. The values of the equilibrium decision variables under product sharing and buy-buy are reported in Table 2.2.

Figure 2.2 provides an illustration of the manufacturer's profits, sales, price and efficiency under the second condition in Proposition 1. It is obvious that a necessary condition for sharing economy to emerge as the unique equilibrium is that the optimal price be greater under sharing than under buy-buy. As mentioned, in Figure 2.2, we can observe that for intermediate values of the volume of high type consumers, β , i.e., in the highlighted region, the price p^{*sh} is higher than p^{*bb} , but it is linearly decreasing in β . This price pattern is due to the fact that for higher β the competition between

⁴Recall that by Assumption 1, $k < 1$ and that the usage need for the high segment is normalized to 1 (i.e., $\theta_H = 1$), whereas the usage need for the low segment, θ_L , is equal to α .

product owners in renting out their product increases. Eventually, when β is neither too low nor too high, then product sharing benefits from sufficiently high margins and a sufficiently high volume of sales (i.e., βM). The equilibrium of sharing economy results from a trade-off between the selling price (which is decreasing in β) and the volume of sales, βM (which is increasing in β).

As we explained, sharing economy arises as the unique equilibrium if $p^{*bb} \leq p^{*sh} = p^{ub}$ and $\Pi^{*bb} \leq \Pi^{*sh}$. However, when such conditions do not hold it is not granted that both segments purchase the product and buy-buy dominates. Sharing economy may still arise as one of two possible equilibria if $p^{lb} \leq p^{*bb} \leq p^{ub}$ and $\Pi^{*bb} \geq \Pi^{*sh}$. There are indeed circumstances under which the manufacturer would make higher profit if both segments purchase the product, but this outcome may not materialize because the price set by the manufacturer to induce both segments to buy would also satisfy the incentive-compatibility constraints under the sharing model. That is, at that price, if all consumers buy, no consumer will have incentive to deviate, but if all high-type consumers buy and rent out and all low-type consumers rent, no consumer will have incentive to deviate either. Therefore, two equilibria may co-exist even if the manufacturer would prefer to sell to both types. The next proposition formalizes this result.

Proposition 2. *When product sharing does not arise as the unique equilibrium it may still arise as one of two possible equilibria (i.e., sharing and buy-buy) if and only if $\alpha > k$ and either $\beta \in [\dot{\beta}_{R_1}, \beta_{R_1}]$ or $\beta \in [\beta_{R_2}, \dot{\beta}_{R_2}]$, where $\dot{\beta}_{R_1}$ and $\dot{\beta}_{R_2}$ are roots of $\Pi^{*bb}(p = p^{lb}) = \Pi^{*sh}(p = p^{ub})$. Otherwise, selling to both segments is the unique equilibrium for the manufacturer.*

Proposition 2 suggests that when consumers have a similar product usage ($\alpha > k$), multiple equilibria of product sharing and buy-buy can arise for values of β neighboring the range $[\beta_{R_1}, \beta_{R_2}]$ (where as per Proposition 1 sharing economy is the unique equilibrium). In all remaining cases, selling to both segments is the unique equilibrium.

Table 2.2: Variable values when product sharing is the unique equilibrium

Variable	product sharing	buy-buy
e^*	$\frac{k}{2c}$	$\frac{k(\alpha-k)}{2c-k^2}$
τ_{Hz}^{O*}	$1 - \frac{(1-\beta)\alpha}{2}$	$\frac{2c(1-k)-k^2(1-\alpha)}{2c-k^2}$
τ_{Lz}^{r*}	$\frac{\alpha\beta}{2}$	—
τ_{Lz}^{O*}	—	$\frac{2c(\alpha-k)}{2c-k^2}$
φ^*	$\frac{k(2c-k)-\alpha(1-\beta)}{k(2c-k)-\alpha(2-\beta)}$	—
w^*	$\frac{\alpha c(2-\beta)-k(2c-k)}{2c}$	—
p^*	$\alpha - k - \frac{\alpha\beta}{2} \left(1 - \frac{\alpha}{2}\right) - \frac{3\alpha^2}{8} + \frac{k^2}{2c}$	$\frac{2c^2(\alpha-k)^2}{(2c-k)^2}$
Π_{pl}^*	$\frac{\alpha^2(1-\beta)\beta M}{4}$	—
Π_f^*	$(\alpha - k - \frac{\alpha\beta}{2} \left(1 - \frac{\alpha}{2}\right) - \frac{3\alpha^2}{8} + \frac{k^2}{4c})\beta M$	$\frac{(\alpha-k)^2 M c}{2c-k^2}$
U_{Hz}^{O*}	$\frac{[2-(2-\beta)\alpha]^2}{8}$	$\frac{(1-\alpha)}{4c-2k^2} [2(1+\alpha-2k) - k^2(1-\alpha)]$
U_{Lz}^{r*}	$\frac{\alpha^2\beta^2}{8}$	—
U_{Lz}^{O*}	—	0

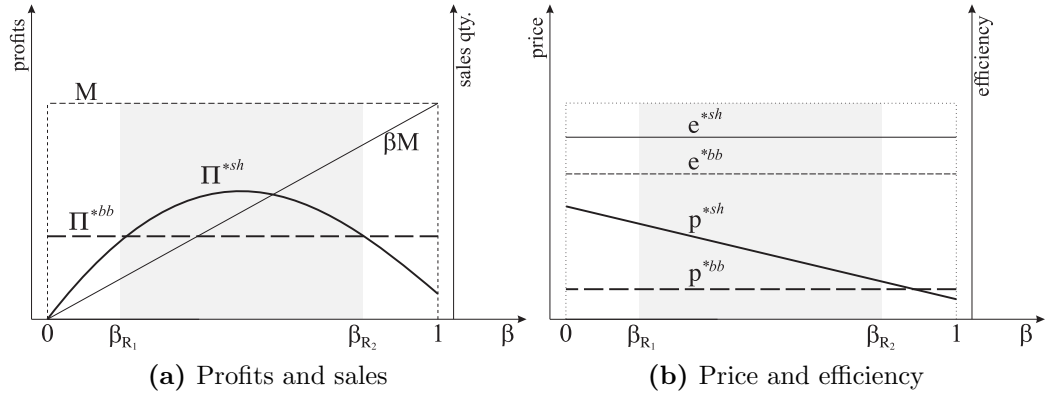


Figure 2.2: The sharing economy as the unique equilibrium

Figure 2.3 illustrates the results of Proposition 2. In the subfigure 2.3a the highlighted region corresponds to values of β where the optimal price under buy-buy falls in the range of prices that are incentive compatible for the activation of sharing economy.

The rationale for the existence of two equilibria in this case is that the emergence of the sharing economy offers a favorable exit option, i.e., renting, that guarantees positive surplus to consumers who decide not to buy (i.e., low-type consumers). As a result, the minimum manufacturer's price that ensures their participation to the sharing economy can sometimes be lower than the price that induces them to buy the product. In the same vein, due to the higher usage need, the maximum manufacturer's price that ensures the participation of high-type consumers to the sharing economy can certainly be higher than the price that induces both segments to purchase the product. Therefore, if the latter price is chosen by the manufacturer, either both segments or only the high type could buy, and in the latter case sharing economy will be activated.

2.4 Comparison on Profits with Other Consumption Models

In this section, we consider the manufacturer's profitability under other two well known consumption models, namely the pure sales model and the servicing model. Then, we compare the profitability of these two models with the one of the sharing economy model. Having derived the conditions under which a peer-to-peer sharing platform enters the market, we are now interested in comparing the manufacturer's profits between the scenario in §2.3, where sharing economy arises as the unique equilibrium (i.e., $\alpha \leq k$ or $\beta \in [\beta_{R_1}, \min\{\beta_{R_2}, 1\}]$), and the two main consumption models in the literature, namely pure sales and servicing.

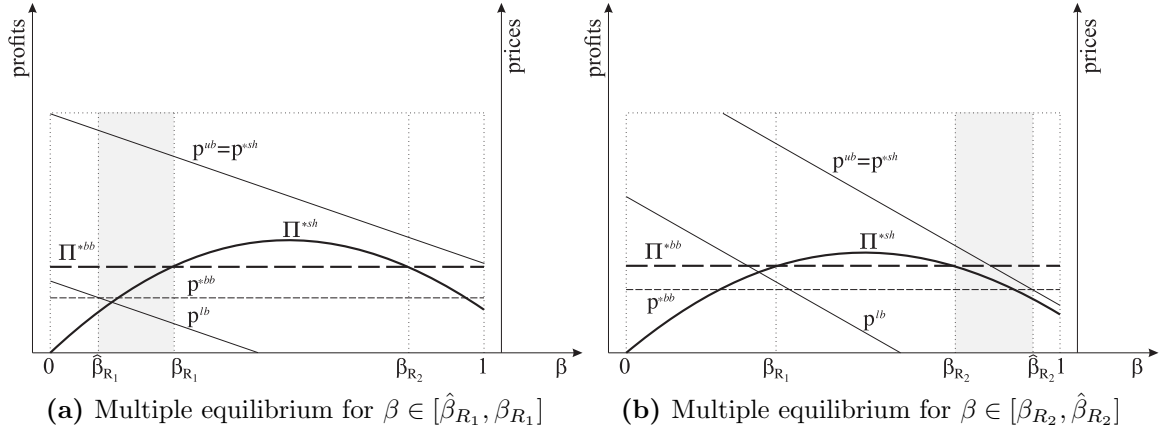


Figure 2.3: The sharing economy as a multiple equilibrium

Through these comparisons, our analysis derives the conditions under which the manufacturer may prefer the presence of a peer-to-peer sharing platform for his product over alternative consumption models.

2.4.1 Pure Sales

In a pure sales model, the sharing platform does not exist. As a consequence, the only possibility for consumers to satisfy their product usage needs is to purchase the product from the manufacturer and use their own product. As usual, the manufacturer has to select the selling price and efficiency, which in turn determine which segment of consumers will purchase the product. Specifically, under a pure sales model, the manufacturer has the option to sell its product to both segments of consumers (same as problem (2.8), which was labeled as “buy-buy” strategy), or only to the high segment of consumers.⁵ We refer to the latter strategy as to “high-buy” and denote it through the superscript “ Hb ”. The manufacturer prefers to sell the product only to the high-segment of consumers instead of to both segments if the number of high-segment consumers, β , is sufficiently high (i.e. $\beta > \beta_{Hb} = \frac{(\alpha-k)^2}{(1-k)^2}$). Under a high-buy strategy the manufacturer is not constrained by the participation constraint of the low-segment consumers and thus will be able to select a higher selling price than the one selected under a buy-buy strategy. It is straightforward, then, to conclude that high-buy will outperform buy-buy when the sales are sufficiently high, that is, β is sufficiently high.

We next compare product efficiency between the sharing economy and pure sales models. In general, the operating cost decreases and thus the product usage increases with efficiency.

Proposition 3. *The manufacturer selects a higher efficiency under sharing economy than under pure sales.*

⁵It is straightforward to demonstrate that selling only to the low segment of consumers is a dominated strategy.

Proposition 3 states that the manufacturer prefers producing a more efficient product under sharing economy than under pure sales. In fact, under either of these models product efficiency drives the selling price up, as the operating cost incurred by the consumers decreases, and thus the product usage and consumers' utility increase with efficiency. However, product efficiency drives the selling price even higher due to a mechanism that emerges only under sharing economy. Specifically, as we said, the product usage of both segments tends to increase with efficiency: owners use more their product if the latter is more efficient, thus leaving less usage available for renters, who would also like to use the product more. This imbalance between low supply and high demand in the rental market leads to higher rental fee. To extract the ensuing consumer surplus, the manufacturer charges a higher price for a more efficient product. As this price increase occurs only under sharing economy, the manufacturer has a greater incentive to increase efficiency under sharing economy than under pure sales

By comparing the pure sales and sharing economy models we can establish under what conditions the manufacturer will prefer the presence to the absence of a platform enabling the sharing of its product. Intuitively, one may think this should never be the case, but the next proposition suggests a different result.

Proposition 4. *Under the conditions where sharing economy arises as a unique equilibrium, the manufacturer's profits are higher under sharing economy than under pure sales if and only if $\beta < \min(\beta'_{R_1}, 1)$*

Proposition 4 derives the conditions under which the manufacturer prefers the presence to the absence of a platform for sharing its product in the market. In Proposition 1, we already showed that when the platform is present product sharing can be the most profitable option for the manufacturer. However, in that case the manufacturer could not sell the product only to the high segment without activating product sharing. The comparison, then, was between product sharing and buy-buy. Here, the platform is absent and the manufacturer has the option to sell only to the

high segment, without implying product sharing. The main result of Proposition 4 is that the region of parameters α, k, β where sharing economy is strictly preferred by the manufacturer still exists, even though it is smaller than the one found in Proposition 1. In particular, we notice that the conditions on β are now more stringent. The reason for a smaller region is that under buy-buy the manufacturer was obliged to set a price sufficiently low to meet the individual rationality constraint of the low-segment consumers. Now, the manufacturer can sell only to the high-segment and thus will set a higher price for its product than the one selected under buy-buy. As a consequence, sharing economy continues to be preferable for a certain range of β . However, since the price under sharing economy decreases with β the supremacy of sharing economy can only occur for a more limited value of β than the one previously found in Proposition 1.

Proposition 4 implies that paradoxically the manufacturer may prefer the presence of a platform for the sharing of its product among consumers. Although counterintuitive there is anecdotal evidence for this result in practice. For example, the company Getaround has raised about 300 million dollar in its latest funding round in 2018, with the scope of expanding in North America and around the world and developing partnerships with automakers. Unexpectedly, one of the major contributors to this funding was Toyota Motor Corp.⁶ The car manufacturer company considers this as a way to decrease the ownership costs for its products. The vehicle owners can put money from renting their vehicle on Getaround directly towards lease payments. The company declared that the presence of Getaround is a way to “decrease the ownership costs for its products”, referring to the fact that the sharing of Toyota’s cars through Getaround is a source of extra rents for cars owners and thus makes their purchase more economically sustainable.⁷

⁶“Car-sharing startup Getaround raises 300 million dollars in funding led by SoftBank”, <https://www.reuters.com/article/us-getaround-funding/car-sharing-startup-getaround-raises-300-million-in-funding-led-by-softbank-idUSKCN1L61BJ>, accessed (8 April 2022)

⁷“Getaround Announces Carsharing Partnership with Toyota”, <https://www.getaround.com/about-press-releases/getaround-announces-carsharing-partnership-with-toyota>, accessed (8 April 2022)

2.4.2 Servicizing business model

Servicizing refers to a business model under which a manufacturer sells the usage of the product rather than the product itself to the consumers while retaining the ownership of the product (Toffel, 2008). There are examples of manufacturers offering only a servicing option (*pure servicing*) and manufacturers offering both sale and servicing options (*hybrid servicing*). For instance, in the automotive industry Zipcar only sells the usage of its cars on demand by the hour, whereas BMW and Daimler both sell cars and their usage (Schmidt, 2020). We use the superscript $\nu \in \{p, h\}$ to denote pure and hybrid servicing, respectively. Under a servicing consumption model, the sequence of events is as follows: (i) the manufacturer decides the servicing option, either pure or hybrid; (ii) the manufacturer selects the per-unit-of-usage price, q , the product efficiency, e , and, in case of hybrid servicing, the sale price, p ; (iii) consumers decide how to satisfy their product usage needs, that is, either by purchasing the use of the product or, in case of hybrid servicing, by purchasing either the use of the product or the product itself; (iv) consumers select their optimal product usage. We assume that consumers are always responsible for the operating cost. The consumption model of servicing has already been extensively studied in the literature (e.g., Agrawal and Bellos 2017). However, to the best of our knowledge, there are no studies that compare sharing economy to servicing from both an economic and environmental point of view. In this section, we study the economic comparison.

Under servicing, the manufacturer benefits from pooling consumers' product usage needs, which reduces the number of products that the manufacturer must produce to satisfy demand (Agrawal and Bellos, 2017). We capture the degree of pooling through the parameter γ , where a higher value of γ means that the manufacturer can meet its customers' usage needs with a lower number of products. To include the effect of pooling into our model, we assume that the number of products needed to fulfill the demand of the servicing market is discounted by a factor $(1 - \gamma)$,

with $\gamma \in [0, \bar{\gamma}]$. Specifically, $\gamma = 0$ means no pooling, in which case the manufacturer needs to produce a number of products equal to the number of consumers (owners plus renters). On the contrary, $\gamma = \bar{\gamma}$ corresponds to the highest level of pooling, in which case, in addition to the products sold to the owners, the manufacturer needs to produce the minimum number of products satisfying the renters' aggregate product usage needs.⁸

Let q denote the pay-per-use price under a servicizing business model. When the manufacturer offers pure servicizing, it sells the usage of the product to both high and low segment consumers. Under pooling degree, γ , the manufacturer will have to solve the following problem :

$$\begin{aligned}
\max_{q,e} \quad & \Pi^p = [q\tau_{H,se}^{*p} - (1 - \gamma)ce^2] M\beta + (1 - \beta)M [q\tau_{L,se}^{*p} - (1 - \gamma)ce^2] \\
s.t. \quad & U_H^p(\tau_{H,se}^{*p}) \geq 0 \\
& U_L^p(\tau_{L,se}^{*p}) \geq 0 \\
& 0 < e < 1,
\end{aligned} \tag{2.9}$$

where the first two inequalities represent the individual rationality constraints (IR) for the high- and low-segments of consumers.

Under hybrid servicizing, the manufacturer offers both sale and servicizing options to consumers, which are denoted through the subscript “sa” and “se”, respectively. It is intuitive that the manufacturer will set up prices so that the high-segment consumers purchase the product, whereas the low-segment consumers rent it. In fact, the usage need is higher for the former than the latter consumers' type, and thus the sale of the product is targeted only to the high-type consumers. Under hybrid servicizing, then, the manufacturer will solve the following optimization problem:

⁸In reality, the upper bound for γ should be endogenously determined, and set equal to the aggregate usage of the low-type consumers (who are those renting the product under hybrid servicizing), i.e., $M(1 - \beta)\tau_L$. However, for tractability reasons, we consider an exogenous upper bound for γ , $\bar{\gamma}$, and ensure that at optimum the aggregate usage of renters is not greater than $M(1 - \beta)(1 - \bar{\gamma})$. It is numerically verified that the results with an endogenous upper bound of γ are the same as those obtained with this simplifying assumption.

$$\begin{aligned}
\max_{p,e,q} \quad & \Pi^h = (p - ce^2)M\beta + [q\tau_{L,se}^{*h} - (1 - \gamma)ce^2]M(1 - \beta) \\
s.t. \quad & U_{H,sa}^h(\tau_{H,sa}^{*h}) \geq U_{H,se}^h(\tau_{H,se}^{*h}) \\
& U_{L,se}^h(\tau_{L,se}^{*h}) \geq U_{L,sa}^h(\tau_{L,sa}^{*h}) \\
& 0 < e < 1,
\end{aligned} \tag{2.10}$$

where the two incentive compatibility (IC) constraints require that high-segment consumers prefer purchasing the product than purchasing the product usage, whereas low-segment consumers have the opposite preference. We next compare product efficiency between the sharing economy and the servicizing model. In a hybrid servicizing model, the manufacturer produces more products, and thus would have an incentive to decrease the efficiency, than in a sharing economy model. However, the manufacturer can charge a higher price for higher efficiency as consumers benefit from lower operating cost. In general, the manufacturer faces the following trade-off when selecting efficiency: the production cost increases whereas the operating cost decreases with efficiency. In particular, the manufacturer can charge a higher selling price for higher efficiency, in the attempt to extract the drop in consumers' operating costs.

Proposition 5. *The manufacturer selects a higher efficiency under sharing economy than under servicizing iff $\gamma < \gamma_e^{se}$.*

In general, the manufacturer faces the following trade-off when selecting efficiency: the operating cost decreases, whereas the production cost increases with efficiency. In particular, the manufacturer can charge a higher selling price for higher efficiency, to extract the surplus due to the lower consumers' operating costs. Therefore, under both sharing economy and servicizing higher product efficiency leading to a lower operating costs, which enable the manufacturer to set a higher selling price for a more efficient product. Also, the rental fee under sharing economy and the per-unit-usage rental price under servicizing increase with efficiency as consumers benefit from lower operating cost. Under a servicizing business model, the manufacturer

fully appropriates the benefits from a higher per-unit-usage rental price, because the latter price increase leads to a direct increase of the manufacturer's revenues. However, under a sharing economy business model, the manufacturer can appropriate the benefits from a higher rental price only partially. This is because the latter price increase augments the revenues of both product owners and sharing platform, whereas the manufacturer can extract only the surplus of the owners through the selling price. As a result, the manufacturer obtains higher revenues by increasing the efficiency under servicing than sharing economy.

On the contrary, higher product efficiency results in higher production cost. Under hybrid servicing, the manufacturer produces a higher number of products than under sharing economy. As a consequence, the manufacturer incurs a higher production cost by increasing the efficiency under hybrid servicing than under sharing economy. The increase in total production cost dominates the increase in revenues under hybrid servicing when pooling effect is sufficiently low. Also, under pure servicing when pooling effect is sufficiently low the increase in total production cost dominates the increase in revenues. As a consequence, the manufacturer chooses a higher efficiency under sharing economy than under servicing when pooling effect is sufficiently low.

We next focus on determining under which conditions sharing economy is more profitable to the manufacturer than servicing.

Proposition 6. *Under the conditions where sharing economy arises as a unique equilibrium, the manufacturer's profits are higher under sharing economy than hybrid servicing if and only if $c \leq c_{se}$ and $\gamma \leq \gamma_{se}$ (the expressions of γ_{se} and c_{se} can be found in the Appendix).*

Under the conditions in Proposition 6 sharing economy is the most profitable business model to the manufacturer. As compared to Proposition 4, which established the superior performance of sharing economy over pure sales model, there are two additional conditions here.

First, consider hybrid servicizing. One may argue that the manufacturer should always be better off under this business model than under sharing economy. In fact, under either model, the volume of product sales is the same and equal to the number of high-type consumers, but hybrid servicizing offers an additional stream of revenues to the manufacturer, due to the product usage sale to the low-type consumers. However, sharing economy has two main advantages. First, the selling price charged by the manufacturer is higher under product sharing than under hybrid servicizing, due to the manufacturer trying to extract the extra rents attained by product owners through product sharing. This first advantage in price cannot be too large as a portion of the owners' extra rents are also intercepted by the platform (double marginalization). Second, the manufacturer needs to produce less products under sharing economy than under hybrid servicizing, which also implies a lower production cost. Therefore, it is clear that the benefit of sharing economy is more prominent for products with weaker pooling effect.

Consider now pure servicizing. Its main advantage over sharing economy is that the manufacturer can pool the product usage needs among both high- and low-segment consumers. Strong pooling decreases the production cost and increases the aggregate usage, both of which make pure servicizing more profitable to the manufacturer than sharing economy. However, when the level of pooling is limited, this advantage of pure servicizing cannot materialize, and the manufacturer prefers sharing economy over pure servicizing. As we mention in Proposition 5, weak pooling increases production cost and decreases the efficiency which implies higher operation cost and lower aggregate usage, which both hurt pure servicizing. The values of the equilibrium decision variables under pure servicizing and hybrid servicizing are reported in Table 2.3.

2.5 The environmental impact

The environmental impact of a consumption model is measured based on two different phases of the product life cycle: the production and the usage phase ([Atasu and Souza, 2013](#); [Agrawal and Bellos, 2017](#)). Let η_p and η_u denote the environmental impact per unit of product during the production phase and the one per unit of product usage during the usage phase, respectively. The total environmental impact during the production phase depends on η_p and the total production quantity (Q) and during the usage phase depends on η_u and the aggregate usage. Therefore the total environmental impact is given by:

$$EN = \eta_p * Q + M\eta_u * (\beta\tau_H + (1 - \beta)\tau_L) \quad (2.11)$$

The environmental impact during the usage phase, production phase and in total under sharing economy, pure sales, and servicizing after substituting the optimal efficiency and the optimal usage are reported in [Table 2.4](#).

From an environmental point of view, the sharing economy business model has both advantages and disadvantages as compared to other business models. On the positive side, it requires the production of products only for the high segment. Further, the manufacturer has an incentive to produce a product of high efficiency, as owners who rent out their product for extra money are willing to pay an extra charge for it. On the negative side, however, sharing economy increases the accessibility to, and thus the use of the product. We next discuss the environmental performance of sharing, pure sales, and servicizing business models.

Table 2.3: Equilibrium values of servicizing business model.

Note that $X = \left((\beta\gamma - \gamma + 1) \left(\left(k + \frac{\alpha}{2} - \frac{3}{2} \right) \beta - \frac{3k}{2} - \frac{\alpha}{2} + 2 \right) c - \frac{k^2(\alpha-1)(\beta-1)}{2} \right)$.

Variable	Hybrid Servicizing	Pure Servicizing
e^*	$\frac{k(k-\alpha-\beta+\beta\alpha)}{2(\beta-2)(\gamma\beta-\gamma+1)c+k^2}$	$\frac{k(\alpha+\beta+\alpha-k-\alpha\beta)}{4c(1-\gamma)-k^2}$
$\tau_{H,se}^*$	$\frac{-2(\beta-2)(k-1)(\gamma\beta-\gamma+1)c+k^2(\alpha-1)(\beta-1)}{2(\beta-2)(\gamma\beta-\gamma+1)c+k^2}$	$\frac{2(-1+\gamma)(k+(1-\beta)\alpha+\beta-2)c-k^2(1-\alpha)(1-\beta)}{4c(1-\gamma)-k^2}$
$\tau_{L,se}^*$	$\frac{-2(\beta(k-1)-k+\alpha)(\gamma\beta-\gamma+1)c+k^2\beta(\alpha-1)}{2(\beta-2)(\gamma\beta-\gamma+1)c+k^2}$	$\frac{2(-1+\gamma)((-\alpha+1)\beta+k-\alpha)c+k^2\beta(1-\alpha)}{4c(1-\gamma)-k^2}$
$\tau_{aggregate}$	$\frac{2c(\beta\gamma-\gamma+1)((\alpha-1)\beta+k-\alpha)}{2(\beta-2)(\beta\gamma-\gamma+1)c+k^2}$	$\frac{2(1-\gamma)(\beta+\alpha-k+\beta\alpha)}{4c(1-\gamma)-k^2}$
q^*	$\frac{2((\alpha-1)\beta+k-\alpha)(\gamma\beta-\gamma+1)c}{2(\beta-2)(\gamma\beta-\gamma+1)c+k^2}$	$\frac{2(1-\gamma)c(\beta+\alpha-k-\beta\alpha)}{4c(1-\gamma)-k^2}$
p^*	$-\frac{c(\beta\gamma-\gamma+1)((\alpha-1)\beta+k-\alpha)X}{((\beta-2)(\beta\gamma-\gamma+1)c+\frac{k^2}{2})^2}$	—
Π_f^*	$\frac{(\gamma\beta-\gamma+1)c((\alpha-1)\beta+k-\alpha)^2M}{2(\beta-2)(\gamma\beta-\gamma+1)c+k^2}$	$\frac{(1-\gamma)((\beta-1)\alpha-\beta+k)^2cM}{4c(1-\gamma)-k^2}$
$U_{H,se}^*$	$\frac{\left((k+\alpha-2)(\gamma\beta-\gamma+1)c - \frac{k^2(\alpha-1)}{2} \right)^2 (\beta-1)^2}{2\left((\beta-2)(\gamma\beta-\gamma+1)c + \frac{k^2}{2} \right)^2}$	$\frac{2\left((-1+\gamma)(k+(1-\beta)\alpha+\beta-2)c - \frac{k^2(\alpha-1)(\beta-1)}{2} \right)^2}{(4\gamma c+k^2-4c)^2}$
$U_{L,se}^*$	$\frac{\left((\beta(k-1)-k+\alpha)(\gamma\beta-\gamma+1)c - \frac{k^2\beta(\alpha-1)}{2} \right)^2}{2\left((\beta-2)(\gamma\beta-\gamma+1)c + \frac{k^2}{2} \right)^2}$	$\frac{2\left((-1+\gamma)((-\alpha+1)\beta+k-\alpha)c - \frac{k^2\beta(\alpha-1)}{2} \right)^2}{(4\gamma c+k^2-4c)^2}$

Table 2.4: The environmental impact for the consumption models under analysis.

Note that $X = \frac{2c(\alpha-k)}{2c-k^2}$, $Y = \eta_u \frac{2c(1-\gamma+\gamma\beta)((\alpha-k)+\beta(1-\alpha))}{2(-\beta+2)(\beta\gamma-\gamma+1)c-k^2}$

Model	Environmental Impact		
	Usage Phase	Production Phase	Total
Sharing economy	$\eta_u M \beta$	$\eta_p M \beta$	$M \beta (\eta_u + \eta_p)$
Pure Sales	$\begin{cases} \eta_u M \beta \frac{2c(1-k)}{2c-k^2}, & \text{if } \beta > \beta_{Hb} \\ \eta_u M [(1-\alpha)\beta + X], & \text{otherwise} \end{cases}$	$\begin{cases} \eta_p M \beta, & \text{if } \beta > \beta_{Hb} \\ \eta_p M, & \text{otherwise} \end{cases}$	$\begin{cases} M \beta (\eta_p + \frac{2c(1-k)}{2c-k^2}), & \text{if } \beta > \beta_{Hb} \\ M [(1-\alpha)\beta + X] \eta_u + \eta_p, & \text{otherwise} \end{cases}$
Hybrid Servicizing	Y	$\eta_p M (\beta + (1-\gamma)(1-\beta))$	$Y + \eta_p M (\beta + (1-\gamma)(1-\beta))$
Pure Servicizing	$\eta_u \frac{2(1-\gamma)cM(\beta-k+(1-\beta)\alpha)}{4c(1-\gamma)-k^2}$	$M(1-\gamma)\eta_p$	$\eta_u \frac{2(1-\gamma)cM(\beta-k+(1-\beta)\alpha)}{4c(1-\gamma)-k^2} + M(1-\gamma)\eta_p$

Proposition 7. *From an environmental perspective, sharing economy is environmentally superior to pure sales model if $\alpha > k$, $\beta \leq \frac{(\alpha-k)^2}{(1-k)^2} = \beta_{Hb}$ and $\frac{\eta_p}{\eta_u} > \frac{\alpha\beta(2c-k^2)-2c(\alpha-k)}{(2c-k^2)(1-\beta)} = \omega^{sh}$.*

Proposition 7 compares sharing economy with a pure sales model from an environmental perspective. When the heterogeneity in product usage need between high-and low-segment of consumers and the portion of high- segment consumer are sufficiently low (i.e. $\beta \leq \beta_{Hb}$) under pure sales model, the manufacturer prefers to sell the product to both high-and low-segment of consumers. Under this condition, clearly sharing economy has always an environmental advantage over pure sales during the production phase, since it needs to produce product only for high-segment consumers. However during the usage phase this may not happen, since both high- and low-segment consumers use the product under sharing economy. The environmental impact during the usage phase under sharing economy is lower than that under pure sales model, if the portion of high-segment consumers is sufficiently low (i.e., $\beta < \beta_{en}$). This condition is a sufficient condition to hold Proposition 7. Therefore, under this condition sharing economy has an advantage over pure sales in both production phase and usage phase. However, if the environmental impact during the usage phase under sharing economy is higher than that under pure sales model, then sharing economy is environmentally superior to pure sales for the products whose environmental impact is mainly determined by the production phase (i.e., $\frac{\eta_p}{\eta_u} > \omega^{sh}$), such as heavy machinery, computers, and tires (Agrawal and Bellos, 2017).

When the portion of high segment consumers or heterogeneity in product usage need are sufficiently high (i.e., $\beta > \beta_{Hb}$ or $\alpha < k$), then the manufacturer prefers to sell the product to only high segment of the consumers rather than both under pure sales model. Then, the environmental impact during the production phase is the same under sharing as under pure sales. However, sharing economy necessarily involves a higher usage of the product since the product has been used by both high and low segment of consumers, and thus it is always environmentally inferior

to pure sales model if the portion of high segment consumers is sufficiently high. Therefore, in contrast to conventional wisdom, sharing economy is not granted to be environmentally superior to pure sales model

We proceed with the analysis of the environmental impact, and compare sharing economy with servicizing. The next result formalizes the results for hybrid servicizing.

Proposition 8. *Sharing economy is environmentally superior to hybrid servicizing if and only if $\frac{\eta_p}{\eta_u} > \omega_{se}^h = \frac{-2(-\beta^2 + (\alpha+1)\beta + k - \alpha)(\beta\gamma - \gamma + 1)c + \beta k^2}{2(1-\gamma)(1-\beta)((\beta-2)(\beta\gamma - \gamma + 1)c + \frac{k^2}{2})}$.*

Clearly, sharing economy has an environmental advantage over hybrid servicizing in the production phase, as it requires to produce products only for the high-segment consumers. However, this advantage may not materialize in the usage phase, since under sharing economy as well as under hybrid servicizing both high and low-segment consumers use the product. The condition in Proposition 8 states that if the total environmental impact is mainly determined in the production phase ($\frac{\eta_p}{\eta_u} > \omega_{se}^h$) then sharing economy will be environmentally superior to hybrid servicizing as it leverages on the previously mentioned advantage. Note that when the pooling effect is sufficiently high (i.e., $\gamma > \gamma_{en} = \frac{2c\beta^2 + ((-2\alpha - 2)c + k^2)\beta - 2c(-\alpha + k)}{2(-\beta^2 + (\alpha+1)\beta + k - \alpha)(\beta - 1)c}$) this condition is always satisfied. The intuition for this result is that the production quantity, and thus the production cost, decreases with the level of pooling, which in turn motivates the manufacturer to increase the product efficiency. This increase in efficiency stimulates higher product usage under hybrid servicizing, which combined with the higher production quantity, leads to a higher environmental deterioration under hybrid servicizing than under sharing economy. Therefore, Proposition 8 implies that hybrid servicizing is environmentally superior to sharing economy only when the pooling effect is limited and the environmental impact is mainly determined in the usage phase.

Proposition 9. *Sharing economy is environmentally superior to pure servicizing under either of the following conditions:*

1. $\gamma < 1 - \beta$ and $\frac{\eta_p}{\eta_u} > \omega_{se}^p$

$$2. \gamma > 1 - \beta \text{ and } \frac{\eta_p}{\eta_u} < \omega_{se}^p$$

$$\text{which } \omega_{se}^p = \frac{2c(k-\alpha+(1+\alpha)\beta)(1-\gamma)-k^2\beta}{(4c(1-\gamma)-k^2)((1-\gamma)-\beta)}.$$

Proposition 9 compares sharing economy with pure servicizing from an environmental perspective. The number of products produced under pure servicizing and sharing economy is equal to $(1 - \gamma)M$ and βM , respectively. If $\gamma < (1 - \beta)$, then, the environmental impact during the production phase under sharing economy is lower than that under pure servicizing as it requires to produce less products than pure servicizing to meet consumers' needs. Therefore, for all product categories where the production phase has a sufficiently higher environmental impact than the usage phase sharing economy will be environmental superior to the pure servicizing. However, pooling effect under pure servicizing has effect on usage as well as number of production. Under strong pooling effect, on one hand number of products decreases but on the other hand the aggregate usage increases. Therefore, the condition $\gamma > (1 - \beta)$, can give an advantage to pure servicizing during the production phase since the number of products produced under pure servicizing is lower than that under sharing economy, but an advantage to sharing economy during the usage phase, as strong pooling effect incentivizes the manufacturer to increase efficiency and thus boosts aggregate usage under pure servicizing. Under this circumstance, sharing economy becomes environmentally superior to pure servicizing if its advantage during usage phase dominates.

Notice that the expression ω_{se}^p is negative if consumers' heterogeneity in product usage need is sufficiently low (i.e. α is sufficiently high). This condition is sufficient condition to hold $\frac{\eta_p}{\eta_u} > \omega_{se}^p$. In particular, the product usage of low segment consumers, and thus the total product usage, increases in α . Therefore, weak pooling effect and low consumers' heterogeneity in product usage need guarantee that sharing economy has an advantage over pure servicizing in both production phase and the usage phase.

2.6 Discussion

We have determined so far when sharing economy is more profitable and environmentally superior than pure sales and servicing. Now, we are interested to summarize the results of the previous analysis and study under what conditions sharing economy is a *win-win* strategy, that is, it simultaneously maximizes the manufacturer's profit and minimizes the environmental impact as compared to the other models.

We start this discussion by noticing at first that sharing economy can never emerge as a *win-win* strategy when under a pure sales model it would be optimal for the manufacturer to sell its product only to the high-segment consumers. Such a manufacturer's selling strategy occurs when the heterogeneity in product usage need between the two segments of consumers (i.e., $\alpha \leq k$) or the portion of high-segment consumers is sufficiently high (i.e., $\beta > \beta_{Hb}$). In this case, even though sharing economy can outperform the pure sales model from profitability perspective but it can never be superior to it from an environmental perspective. Also, when the level of pooling, γ , is sufficiently high, the manufacturer's profit is higher under servicing than sharing economy, but it is environmentally inferior to it. Given these examples, it is not obvious whether product sharing can result in a *win-win* outcome. However, the following proposition suggest that there is a non-empty parameters space, where product sharing is more is both more profitable to the manufacturer and environmentally superior as compared to the other consumption models.

Proposition 10. *Product sharing can be both more profitable to the manufacturer and environmentally superior (win-win) as compared to the consumption models of pure sales and hybrid servicing.*

According to Proposition 4 and 6, sharing economy is more profitable to the manufacturer than pure sales and it is environmentally superior to pure sales when the heterogeneity in product usage need is sufficiently low and the portion of high-segment consumers is sufficiently low (i.e., $\alpha > k$ and $\beta \in [\beta_{R1}, \min(\beta_{Hb}, \beta'_{R1}, 1)]$) for products whose environmental impact is mainly determined by the production

phase rather than the usage phase (i.e., $\frac{\eta_p}{\eta_u}$ is sufficiently high). Instead, according to Propositions 6, 8, and 9, sharing economy is more profitable to the manufacturer than servicing and environmentally superior to it if pooling effect is sufficiently low or marginal production cost is sufficiently high for products whose environmental impact is mainly determined by the production phase rather than the usage phase. Proposition 10 states that the space identified by all these conditions is not empty, thus implying that sharing economy can result in a *win-win* outcome.

We start this discussion by noticing at first that sharing economy can never emerge as a *win-win* strategy when under a pure sales model it would be optimal for the manufacturer to sell its product only to the high-segment consumers. Such a manufacturer's selling strategy occurs when the heterogeneity in product usage need between the two segments of consumers (i.e., $\alpha \leq k$) or the portion of high-segment consumers is sufficiently high (i.e., $\beta > \beta_{Hb}$). In this case, even though sharing economy can outperform the pure sales model from profitability perspective but it can never be superior to it from an environmental perspective. Also, when the level of pooling, γ , is sufficiently high, the manufacturer's profit is higher under servicing than sharing economy, but it is environmentally inferior to it. Given these examples, it is not obvious whether product sharing can result in a *win-win* outcome. However, the following proposition suggest that there is a non-empty parameters space, where product sharing is more is both more profitable to the manufacturer and environmentally superior as compared to the other consumption models.

Figure 2.4 depicts different outcomes that emerge when peer-to-peer sharing economy is compared with pure sales and servicing depending on values of portion of high-segment consumers (i.e., β) and of degree of pooling (i.e., γ) for the for products whose environmental impact is mainly determined by the production phase rather than the usage phase (i.e., $\frac{\eta_p}{\eta_u}$ is sufficiently high). Restricting the analysis to the range of β where sharing economy can arise as a unique equilibrium (i.e., $\beta_{R_1} \leq \beta \leq \beta_{R_2}$, see Proposition 1) the figure illustrates that sharing economy results in a win-win outcome, when the pooling effect is sufficiently low and the portion of high-segment

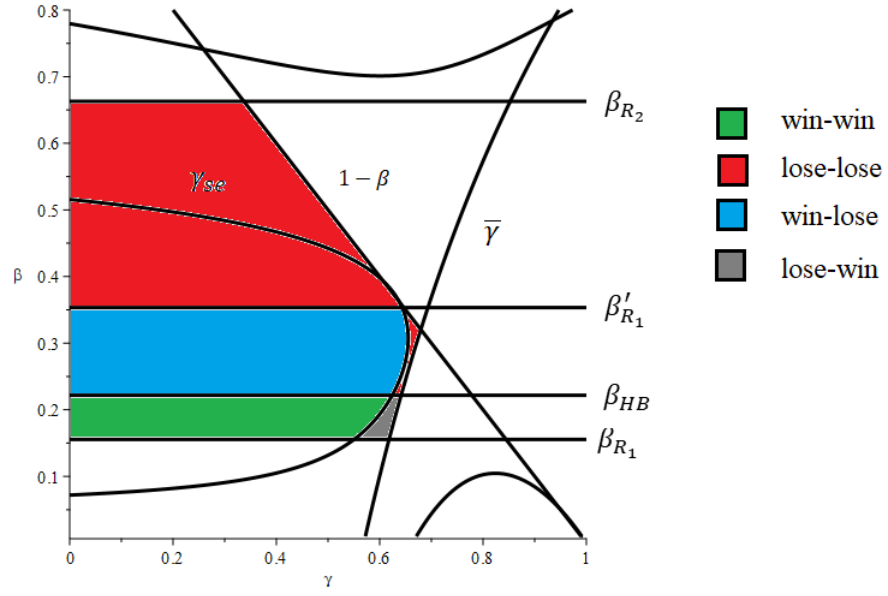


Figure 2.4: Different strategies in terms of γ and β

consumers are neither too low nor too high. However, if the pooling effect and portion of high-segment consumers are sufficiently high then peer-to-peer product sharing results in a lose-lose outcome. Furthermore, if all else equal the pooling effect increases too much, then sharing economy will be resulting in a win-lose situation.

2.7 Conclusion

Sharing economy business models have received much attention from environmental groups and agencies in an attempt to assess whether they are more “green” than other consumption models. When consumers share their products with each other the number of product purchases may diminish, but the access to the product, and thus its usage, may increase. As a consequence, the overall environmental impact of sharing economy is not clear. Motivated by this, our research offers insight for the manufacturers and environmental agencies regarding when and why sharing economy can be simultaneously more profitable to the manufacturer and environmentally beneficial. Our research studies the conditions under which sharing economy arises as a unique equilibrium and then compares this business model with the other two main consumption models available in real business settings, namely pure sales and hybrid servicizing, in terms of both manufacturer’s profit and environmental impact.

Our study finds that, in a setting where the manufacturer only sells the product, sharing economy emerges as a unique equilibrium when the heterogeneity in product usage need between high- and low-segment consumers is sufficiently high or the portion of high-segment consumers is neither too low nor too high. A large heterogeneity in product usage need intuitively implies that consumers may be more profitably satisfied with separate consumption models. That is, consumers with high product usage need would be willing to purchase the product, whereas consumers with low product usage need would rent it through the sharing economy platform. When the heterogeneity in product usage need is not sufficiently large, sharing economy can still arise as a unique equilibrium if the sizes of the two types of consumers are not too

polarized. If there are too few consumers with high product usage need (i.e., those consumers who actually purchase the product), the number of product units sold by the manufacturer would be very limited, which would not be compensated by the higher price the sharing economy can enable. On the contrary, if there are too many consumers with high product usage need, the competition among product owners in renting out their product through the sharing economy platform would result into a low rental fee. In turn, the manufacturer would have a lower surplus to extract from the product owners, thus being unable to charge a high selling price for his product. When the sizes of low and high usage need segments are too polarized, the manufacturer prefers selling the product to both types of segments, and the sharing economy will not materialize.

The comparison of the sharing economy model with pure sales and hybrid servicizing allows us to derive a number of important results. First, the manufacturer always produces more efficient products under sharing economy than under pure sales, whereas products will be more efficient under sharing economy than under hybrid servicizing only if the pooling effect of servicizing is sufficiently limited. While product efficiency drives the product price up irrespective of the consumption model due to the reduction of operating costs incurred by consumers when using the product (e.g., fuel in the case of cars), in the presence of sharing economy a higher product efficiency favor even higher product price. This is because product owners use more their product if the latter is more efficient, thus leaving less usage available for renters, who would also like to use the product more. This imbalance between low supply and high demand in the rental market leads to higher rental fee. The manufacturer can therefore further raise the product price under sharing economy in the attempt to appropriate the higher surplus product owners can generate from such higher rental fee. This unique feature of the sharing economy model would determine a higher product efficiency when compared to pure sales, but not necessarily when compared to servicizing. This is because under the latter model the manufacturer can benefit not only from the higher selling price, but also from entirely appropriating the higher

per-unit-usage rental fee a higher product efficiency entails. This benefit of servicizing results into a lower efficiency as compared to the sharing economy model only when the pooling effect of servicizing is sufficiently small, as in this case the incentive to increase efficiency would be weakened by the larger production cost that servicizing implies.

Importantly, we also find that the sharing economy can be a viable model for both the manufacturer and the environment. In fact, we find that the manufacturer can make higher profit under the sharing economy than under both pure sales and servicizing consumption models, especially when consumers with high and low usage need, respectively, are of similar size, and the pooling effect of servicizing is sufficiently limited. Under these conditions, the sharing economy model will likely result in a significantly higher selling price, thus raising profits compared to the other consumption models. Moreover, we find that the sharing economy model can be less detrimental to the environment than both pure sales and servicizing, especially for product categories for which the environmental impact is mostly driven by the product production than by its usage and when the portion of consumers characterized by high usage need is relatively limited. In particular, our results show the existence of a considerable non-empty region where the sharing economy model is both more profitable for the manufacturer and environmentally superior than the other two consumption models. In other words, it is possible that the sharing economy realizes a win-win for both manufacturer's profitability and the environment.

Our results offer remarkable implications for both theory and practice. As for theory, we first complement the findings of prior literature by revealing how the profitability advantage of the sharing economy for manufacturers depends not only on product costs, but also on some market characteristics. In particular, while prior studies (e.g., [Jiang and Tian 2018](#)) have shown that the sharing economy model can yield a higher profit for the manufacturer than the traditional pure sales model when product marginal costs are sufficiently large, we show that this can also occur when consumers differ substantially in their product usage need and/or the size of

consumers with different product usage need is similar. Second, our research informs the extant literature focusing on the environmental impact of different consumption models (e.g., [Agrawal and Bellos \(2017\)](#), [Örsdemir et al. 2019](#)) that under certain conditions the sharing economy model may be considered more environmentally friendly than other traditional models, such as sales and servicizing models. In this regard, our results highlight that the sharing economy can provide manufacturers with an incentive to produce more efficient products compared to other consumption models. Third, prior research examining the sharing economy model has mostly been confined to the profitability comparison with other consumption models (e.g., [Jiang and Tian 2018](#), [Abhishek et al. 2021](#)). Our findings imply that when making such comparison, it is important consider both profitability and environmental impact perspectives because these two goals are not necessarily aligned. In this regard, our results enhance the understanding on when and why the sharing economy can emerge as a win-win model for both the manufacturer and the environment.

As for practice, our results offer important insights for managers and policy makers. First, they suggest that manufacturers may want to embrace sharing economy, especially in markets (e.g., car industry) very heterogeneous in terms of product usage need and balanced in size between consumers with high and low product usage need. In these settings, despite possibly reducing the demand, product sharing can enable significantly higher product prices, which will turn into higher profits. Second, by adopting the sharing economy model, manufacturers will be stimulated to develop more efficient products. In particular, manufacturers, environmentalists, and policy makers should be aware that the business models that lead to the highest product efficiency (e.g., lowest fuel consumption) are either sharing economy or hybrid servicizing depending on the pooling ability of the latter type of model. Third, as we mentioned earlier in the paper, there are contrasting views about whether sharing economy can be environmentally friendly. Our findings conmanufacturer these contrasting views as they suggest that the sharing economy can be environmentally superior or inferior to other consumption models. For instance,

we inform environmentalists and policy makers that the sharing economy is the less impactful model for the environmental, especially for product categories where production (rather than usage) is the most important driver of the environmental impact and when the portion of consumers characterized by high usage need is relatively limited. For other product categories, sharing economy may result in an detriment to the environment. Finally, given our win-win result, we believe it is of great interest for manufacturers and policy makers to know that there is enough room for manufacturers to pursue both the objectives of profitability and environmental impact under the sharing economy.

There are several avenues of further research that can originate from our work. First, to facilitate tractability in our comparisons, we have considered deterministic usage needs. Future studies could enrich our setting by introducing consumers' uncertainty in their usage needs. Second, as discussed earlier, in modeling the setting where a sharing economy platform can enter the market we have assumed that the manufacturer adopts a pure sales model. We have explained that if instead the manufacturer initially utilizes a hybrid servicizing model, then the entry of the sharing economy platform would result in a competitive rental market (i.e., renters could decide to rent directly from the manufacturer or through the sharing economy platform). In this case, without any rental service differentiation between the manufacturer and the sharing economy platform, the competition would result in a Bertrand outcome. This implies that the manufacturer would either not accommodate the platform by keeping using the hybrid servicizing model or welcome it by switching to a pure sales model, depending on which model results in higher profit. Both scenarios are already considered in our current study because the first scenario is our hybrid servicizing model, whereas the second scenario is our sharing economy model. Therefore, without service differentiation, the case where the manufacturer initially adopts a hybrid servicizing model becomes irrelevant as the relative results can be derived from the present study. Future studies could instead investigate the case where there exists service differentiation between the manufacturer and the sharing

economy platform in the rental market to understand how this will affect our findings. Third, to focus on the intrinsic effects of the sharing economy on manufacturer's profitability and the environment, our model considers a monopoly model for both the manufacturer and the platform. In future studies it would be interesting to introduce competition in the manufacturer's market and/or in the platform market to understand how competition in the different stages will shape the economic and environmental performance of the sharing economy.

Chapter 3

The Impact of Sharing Economy on Innovation and Profitability: An Empirical Study in the Automotive Industry

3.1 Introduction

“Innovation, the process of bringing new products and services to market” (Hauser et al., 2006) is an important issue to stockholders such as manufacturer managers, employees, investors, and regulators because it has an influential impact on companies’ competitive advantages (Porter, 1992; Fang et al., 2014). Given the importance of innovation for manufacturer and national level competitiveness, a growing literature has examined the effect of various factors on innovation, such as the effect of acquisition, stock liquidity, bank competition, technology shock, and supply chain network. (Zhao, 2009; Fang et al., 2014; Cornaggia et al., 2015; Schilling, 2015; Chu et al., 2019). However, the existing literature has overlooked the effect of sharing economy on innovation.

Sharing economy refers to business models where consumers can share an underutilized resource through an online platform that matches supply and demand for the usage of that resource. In some cases, consumers may share their time or provision services through platforms, such as Uber and Lyft for transportation services or TaskRabbit for household tasks. This example of sharing economy is referred to as “on-demand product sharing” (Benjaafar and Hu, 2020), and this is the focus of this work. In some other cases, consumers may share their tangible asset or product through platforms, such as Getaround for cars, VRBO for accommodation, 3D Hubs for 3D printers, and Spinlister for bikes. The latter example of sharing economy is also referred to as “peer-to-peer product sharing” (Tian and Jiang, 2018; Benjaafar and Hu, 2020).

The on-demand sharing economy have experienced rapid growth. For example, in 2017 19% of adult population in major cities in the United States used ride-hailing platforms (Clewlow and Mishra, 2017). These business models have received much attention from practitioners to determine the effect of sharing economy on social welfare, manufacturers, and consumers. As an example, Cachon et al. (2017) investigate how the platform should determine their service fee, and how much they should pay their workers. Bellos et al. (2017) consider the effect of car-sharing on an original equipment manufacturer (OEM) and its product line design. Gong et al. (2017) investigate the effect of Uber entry on purchase demand in China. However, there is no study to investigate the effect of on-demand sharing economy on manufacturers’ profitability and innovation.

The impact of on-demand product sharing on manufacturers’ profitability and innovation is not clear because it has two different effects on demand. On one hand, product sharing may decrease ownership because consumers have renting options besides purchasing (*a cannibalization effect*) (Jiang and Tian, 2018). For example, ride-hailing platforms such as Uber and Lyft provide a cost-effective transportation options (Cramer and Krueger, 2016). Therefore, the manufacturer’s profitability will decrease which may hurt innovation. On the other hand, it can make the ownership

more attractive because they can obtain extra income by providing ride-hailing service thorough the sharing platform (*a value enhancement effect*) (Benjaafar and Hu, 2020; Abhishek et al., 2021; Jiang and Tian, 2018). Also, the manufacturer may increase the selling price under the presence of the product sharing platform (Jiang and Tian, 2018). Since owners can obtain extra money by participating in sharing economy, manufacturers will have a higher surplus to extract from the product owners, and thus will be able to charge a high selling price. As a result, the manufacturers' revenue may increase and this may positively impact the incentive for innovation. It is worthwhile to demonstrate these mechanisms are not mutually exclusive and can happen simultaneously. Therefore, it is possible some consumers cannibalize their purchases and others find value enhancement (Gong et al., 2017).

However, analytical studies provide only a positive or negative impact of product sharing on manufacturer's demand, and as a consequence, its profit (Gong et al., 2017). For example, a couple of analytical studies show that ride-sharing emergence leads to reduced vehicle ownership (Cervero et al., 2007; Martin and Shaheen, 2011). Also, ride-hailing may have a direct impact on innovation as well. Consumers who participate in the ride-hailing market demand more reliable products which may have an impact on innovation. Since ride-hailing is growing dramatically, understanding its impact is crucial.

Furthermore, in recent years several companies in the auto manufacturing industry have been involved in the ride-hailing market. For example, GM has invested 500 million dollars in Lyft, Toyota has invested 500 million dollars in Uber, Daimler will be partnered with Uber, and Ford and Google are teaming up to create their own ride-hailing business. Therefore, those companies need to know the underlying impact of ride-hailing on the demand and supply side to make a profit in this market.

Therefore, in this paper, we empirically study the effect of on-demand sharing economy business models on manufacturers' profitability and innovation. In particular, we investigate the impact of the on-demand ride-hailing emergence and growth on

the auto manufacturers' profit and innovation incentives in the United States. Ride-hailing business models such as Uber and Lyft match people who need a ride (or riders) with drivers who are willing to provide it using their vehicles.

We investigate how ride-hailing influences manufacturers' profit and innovation and clarify the nature of the relationship between ride-hailing and innovation. To find this effect, our study empirically addresses two interrelated research questions. First, what is the impact of ride-hailing growth on manufacturers' profitability? Second, what is the impact of ride-hailing growth on innovation with and without controlling profitability? Based on the existing literature, we use both research and development expenditures (R&D), which is an input for innovation, and patent data, which is output for innovation, as proxies to capture the manufacturers' innovation (Zhao, 2009). To empirically test the hypothesized relationship, we collected manufacturer-level, industry-level, and economic-level data from several databases such as the Compustat database. We consider all auto manufacturers and auto parts manufacturers in the US that can be identified in the Compustat database between 2000 to 2019. Also, we use total annual revenue of Uber and Lyft in the US as a proxy to measure the emergence and growth of ride-hailing, and we use manufacturer's annual revenue as a proxy to measure profitability. We use a generalized fixed-effect method to identify the underlying mechanism of the effect of ride-hailing on manufacturer's profit and innovation.

Our study contains several notable findings. First, it suggests that following the emergence and growth of ride-hailing platforms, the manufacturer's profitability increases, indicating that the value enhancement (i.e., earning additional income) through ride-hailing dominates cannibalization. Also, our study shows that ride-hailing growth has a positive significant impact on both innovation input (i.e., R&D) and innovation output (i.e., number of patents). To better identify the underlying mechanism of the effect, we developed two additional models to test for the influence of manufacturer's profitability, as a mediator variable, on the casual relationship between ride-hailing growth variable and innovation variables. A

mediator variable describes the relationship between the dependent (i.e., innovation) and the independent variables (i.e., ride-hailing growth). Mediation analysis tests a hypothetical causal chain where independent variable affects the mediator variable and, in turn, that variable affects the dependent variable. Mediator variables explains of how or why of the relationship between the dependent variable and independent variable (Baron and Kenny, 1986). The results of these two models show that manufacturer’s profitability does in fact partially mediate the relationship between ride-hailing growth and innovation. It means that the main effect of ride-hailing growth on innovation goes through the increasing the manufacturer’s profitability.

This empirical research has important managerial implications for both manufactures and policy-makers. Although ride-hailing platform may decrease the manufacturer’s profitability by reducing consumers’ propensity to own a auto, our results suggest that overall manufacturer’s profitability arises. Also, ride-hailing platforms have both direct and indirect impact on the enhancement of the innovation of the manufacturers. In particular, results provide evidence that the manufacturers may benefit from the emergence of ride-hailing platforms. Therefore, this research provide several significant incentives for the manufacturers to advocate the emergence and growth of ride-hailing platforms.

The rest of our paper proceeds as follows. The literature is reviewed in Section 2, where we also develop and formally state our hypotheses. Our data and methods are described in Section 3, and Section 4 presents the results. We conclude in Section 5 with a summary discussion and some suggestions for future research.

3.2 Theory and Hypotheses

We depict the connection among ride-hailing, manufacturer’s profitability and its innovation in Figure 3.1. This simple framework enables us to consider the direct effect of ride-hailing growth on profit and innovation (Links a, and b), as well as the

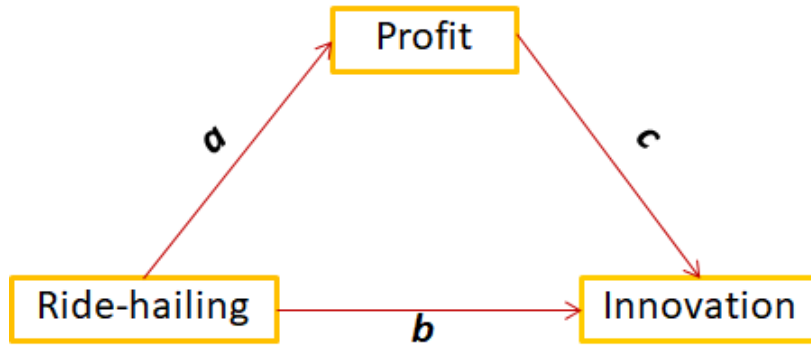


Figure 3.1: Research Framework

mediation effect of manufacturer's profit on the relationship between ride-hailing and innovation (Links a and c).

Link a refers to the impact of ride-hailing growth on manufacturer's profitability. More growth on ride-hailing should increase manufacturer's profitability. According to the literature, the presence of sharing economy affects manufacturer selling demand in two ways. On the one hand, sharing platforms may decrease the ownership because they provide an alternative option (i.e., renting) beside purchasing to use the product (i.e., the product consumers have renting options besides purchasing (*a cannibalization effect*)) (Jiang and Tian, 2018). For example, ride-hailing platforms such as Uber and Lyft provide cost-effective transportation options (Cramer and Krueger, 2016). On the other hand, sharing platform can make the ownership more attractive because owners can obtain excess rents (*a value enhancement effect*) (Benjaafar and Hu, 2020; Abhishek et al., 2021; Jiang and Tian, 2018). Also, the manufacturer may increase the selling price under the presence of the sharing platform (Jiang and Tian, 2018). Because owners can obtain extra money by participating in sharing economy, thus manufacturer can have a higher surplus to extract from the product owners. As a result, the manufacturer will be able to charge a high selling price. Also, sharing economy could lead to a more usage if cost of ownership is sufficiently high. Then, more usage, leading to more frequent product replacement, increasing sales revenue (Benjaafar and Hu, 2020; Fraiberger and Sundararajan, 2017). Therefore, we combine the effect of sharing economy on ownership, selling price and product usage, to propose that ride-hailing as part of sharing economy business model increases manufacturers' profitability. Accordingly, we hypothesize that:

Hypothesis 1. *Ride-hailing has a direct positive effect on manufacturer's profit.*

We also consider the direct effect of sharing economy on innovation (Link b). According to the literature, sharing economy may increase the incentive of the manufacturer to produce more efficient products or higher initial baseline quality

products (e.g., the speed of microprocessors) if they participate in this market (Bellos et al., 2017; Jiang and Tian, 2018; Blaettchen et al., 2018). Because under this business model the consumers with high usage value in one-period willingness to pay a higher selling price may increase, since they anticipate obtaining income by renting out their products during periods when their usage value is not high. This gives an incentive to the manufacturer to invest more money in research and development which may help the manufacturer to be more innovative. Also, manufacturers may choose to acquire mobility companies, to leverage their innovation into their products and services (Spulber et al., 2016). Furthermore, consumers who participate in the ride-hailing market demand more reliable vehicles, which leads to more investment in innovation (Hughes, 2017). Therefore, we expect a positive relationship between sharing economy and particularly ride-hailing and manufacturers' innovation.

Hypothesis 2. *Ride-hailing has a direct positive effect on manufacturer's innovation.*

Finally, with Links a and c, we illustrate our perspective that the manufacturer's profitability, which serves as a mediator, positively mediates the association between ride-hailing growth and innovation. The mediating model proposes that the ride-hailing growth influences the manufacturer's profit (mediator variable), which in turn influences the innovation incentives. According to the literature, sharing economy may increase the selling price or/ and demand which leads to an increase in manufacturer's profitability. Therefore, the manufacturer can invest more in innovation. Also, sharing economy increases the usage of the products and decreases the expected lifetime of the products (Fraiberger and Sundararajan, 2017) which causes a more frequent replacement of the products. This leads to an increase in the manufacturer's profit (Benjaafar and Hu, 2020). Therefore, we expect the manufacturer's profit mediates the relationship between ride-hailing growth and innovation.

Hypothesis 3. *The positive effect of ride-hailing on innovation is partially mediated by the manufacturer's profit*

3.3 Data and Sample Construction

3.3.1 The Sample

To test the above hypotheses, we collect the data of all auto manufacturers with Standard Industrial Classification (SIC) code 3711 and all auto parts manufacturers with SIC code 3714 in the U.S. that can be identified in the Compustat database between 2000 to 2019. Compustat database contains annual, worldwide, company-level information such as revenue, cash, and assets for companies listed in North America. We include only the manufacturing companies which are in “Motor Vehicles and Passenger auto Bodies” and “Motor Vehicle Parts and Accessories”. Standard Industrial Classification (SIC) codes are four-digit numerical codes that the U.S. government assigns to companies to categorize them based on the industry they belong to. The SIC codes were established in 1973 and helped the government to collect statistical data, and classify and analyze economic activities across different industries (Picardo, 2021). You can find more information about this classification on “[naics.com](https://www.naics.com)”. Our sample-selection procedures result in a total of 595 observations and 42 manufacturers.

3.3.2 Dependent Variable

To test our Hypothesis 1, we use manufacturer’s total revenue at each year as a proxy for the manufacturer’s profitability (Hauser et al., 2006). “Total revenue represents gross sales (the amount of actual billings to customers for regular sales completed during the period) reduced by cash discounts, trade discounts, and returned sales and allowances for which credit is given to customers” (Poor’s, 2003).

To test hypotheses 2 and 3, we consider both innovation input and innovation output. Based on existing literature, we use R&D expenditures to measure innovation input. Several studies empirically demonstrate the relationship between R&D and innovation performance (Adams et al., 2006; Greve, 2003). R&D expenditures are

the most important input factor for innovation input. Also, we use number of patents granted in a year as an indicator of the manufacturer’s innovation output (Porter et al., 1999; Katila, 2000; Chu et al., 2019; Wu et al., 2020; Bellamy et al., 2014). This measure captures how effectively the manufacturer has utilized its innovation inputs (Fang et al., 2014). Joshi et al. (2010) shows that the manufacturers that pose a large number of granted patents are more capable of transforming the investment in research and development into new products and services introduced to the market. We use the United States Patent and Trademark database (USPTO) to obtain this information. This database provides bibliographic data, citations, and family links of patents granted by the U.S. The USPTO evaluates patents on specific criteria such as novelty, usefulness, and non-obviousness.

3.3.3 Independent and Control Variables

Ride-hailing companies provide peer-to-peer access to a means of transportation where a person uses a mobile-based platform to “hail” or request a local driver to pick them up and take them directly to a specific location. Uber and Lyft are the largest two ride-hailing platforms in the United States. Uber is known as a leader and pioneer of sharing-economy company in the transportation industry. Uber goes live for the first time in May 2010 in San Francisco, California. After that, it rapidly expanded its market to different cities across the United States, such as New York City, Chicago, and Washington D.C., in May 2011. Currently Uber service is available in 633 cities around the world (Kim et al., 2018). Lyft, the main competitor of Uber in the United States, launches in San Francisco, California in 2012 and expanded to 60 cities across the United States by 2014. Lyft Services is available in 644 cities in the United States and 12 cities in Canada at the current time.¹ Lyft, with a 32% market share, is the second largest ride-hailing company in the United States after Uber.² As a platform-based company, Uber and Lyft are platform-based company to

¹“Lyft”. <https://en.wikipedia.org/wiki?curid=10149406>. (accessed 9 April 2022)

²“Lyft”. <https://en.wikipedia.org/wiki?curid=10149406>. (accessed 9 April 2022)

connect drivers who use their autos to customers who need rides. Passengers submit a trip request through Uber’s or Lyft’s smartphone application, and then drivers who use their own vehicles to satisfy the requests will be assigned to the consumers who submit a trip request.

Uber and Lyft held 98.7% of market share in ride-hailing industry in August 2019 in the United States (Salas, 2019). Therefore, we use the total annual revenue of Lyft and Uber from 2010 to 2019 in the U.S. as an indicator of ride-hailing emergence and growth (Iqbal, 2022). We consider Uber revenue equal to zero from 2000 to 2009 and Lyft revenue equal to zero from 2000 to 2011.

We follow the existing literature (Chu et al., 2019) and control for a vector of time-variant event at economic level, industry level, and manufacturer level variables, that may affect a manufacturer’s profitability and innovation input and output. Control variables in economic level include GDP_t (GDP in trillion at year t) and $Car\ to\ Trips_t$ (ratio between number of registered auto in USA at year t to number of unlinked passengers in USA at year t). In industry level we include $Industry\ Concentration_t$ (Herfindahl-Hirschmann Index) (Bellamy et al., 2014) at SIC codes 3711 and 3714. The use of industry control helps ensure that our findings are robust to industry effects. We follow the existing literature and control for a vector of manufacturer characteristics. The control variables include $Cash_t$ (cash holdings divided by total asset at year t) to control for the manufacturer size, and $Cumulative\ Active\ M\&A_s_t$ (number of M&As where the given company is the acquirer until year t) to control for any change in nature of their business or competitive position. “Mergers and acquisitions (MA) is a general term that describes the consolidation of companies or assets through various types of financial transactions, including mergers, acquisitions, consolidations, tender offers, purchase of assets, and management acquisitions” (Hayes, 2021). To test Hypothesis 3, since the goal is to find the mediating effect of manufacturer’s profitability, we include manufacturer’s revenue as a mediator variable. Financial data at the manufacturer level for the dependant and control variables were retrieved from the Compustat database.

We report all variables definition in Table 3.1. The range of robustness test and examination of errors graphs show that the results are more reliable when all independent variables are log-transformed. The log-transformation decrease the skew in the data.

Table 3.2 provides summary statistics of the variables used in this study. An average each manufacturer has been granted around 83 patents a year. All manufacturers characteristics are comparable to those reported in existing literature. To check the multicollinearity, we implement variation inflation factor (VIF) test for all variables. Since value of VIF for all variables are below 10, no multicollinearity issues are presented in the results.

3.4 Methodology and Empirical Results

To analyze the data, we use STATA. Our data set is unbalanced panel data which contains the observations about various manufacturers across time. Since the levels that we observe in our individual group, which is manufacturer is not a sample from another large population, and to control for unobserved heterogeneity (i.e., the possibility that unmeasured differences among equivalent manufacturers affect their profitability and innovation) we use the fixed-effect method to find the causal effect of ride-sharing on manufacturer's profit and innovation input and output (Clark and Linzer, 2015). The fixed-effect model investigates the causal relationship between predictors and dependent variables within an entity when there are multiple observations for each entity. In our research, the entity is the manufacturer. Each manufacturer has its characteristics that may or may not influence the dependent variables. In the fixed-effect model, we assume we control the effect of unobserved characteristics that varies across entities but are indifferent across time. This is the reasoning for the correlation between an entity's error term and predictor variables in the fixed-effect model. Therefore, applying this model to remove the effect of those (Bai, 2009).

Table 3.1: Variable Definitions

Variable	Definition
Dependent Variables	
Revenue	Natural logarithm of revenue in million
Patents	Number of patents granted
R&D	Natural logarithm of research and development expenditure
Independent Variable	
Ride-hailing Revenue	Natural logarithm of Uber and Lyft revenue in USA
Control Variables	
Economic-level	
GDP	Natural logarithm of real GDP in trillion
Car to Trips	Natural logarithm of the ratio between the number of autos owned and the number of unlinked passengers' trips at time t
Industry-level	
HHI	Natural logarithm of the Herfindahl-Hirschmann Index
Manufacturer-level	
Cumulative Active M&A	Natural logarithm of number of M&As where the given company is the acquirer until year t
Cash	Natural of cash holding divided by total asset

Table 3.2: Summary Statistics

Variable	Mean	std.dev	P25	Median	P75
Revenue	8.9	2.29	7.40	8.83	10.25
Patents	82.59	183.85	2	23	62
R&D	0.042	0.040	0.024	0.032	0.046
Ride-hailing Revenue in million	11.71	10.30	0	15.69	22.16
GDP	9.64	0.21	9.47	9.65	9.81
Car to Trips	0.025	0.001	0.024	0.025	0.026
HHI	7.18	0.2	7.04	7.17	7.26
Cumulative Active M&A	2.77	1.48	1.79	2.94	3.88
Cash	-0.003	0.56	0.04	0.07	1.12

time-invariant characteristics helps us to evaluate the net effect of the predictors on the dependent variables. In all regression models, we use heteroskedasticity-adjusted standard errors that are robust to clustering at the manufacturer level.

3.4.1 Baseline Specification and Results

To test Hypothesis 1, we construct a basic linear regression model to identify the effect of ride-hailing on manufacturers' revenue as follows:

$$\begin{aligned} Revenue_{i\tau} = & \beta_1 Cash_{it} + \beta_2 CumulativeActiveM\&A_{it} + \beta_3 RidehailingRevenue_t \\ & + \beta_4 HHI_{jt} + \beta_5 GDP_t + \beta_6 CartoTrips_t + c_i + u_{it}, \quad t = 1, \dots, T \end{aligned} \quad (3.1)$$

where i indexes manufacturer, j indexes industry, and t indexes time. c_i captures unobserved time-invariant heterogeneities across the manufacturers and u_{it} captures the error. The dependent variable in this model is our measure of the manufacturer's profitability (*Revenue*), measured at time $\tau = t, t + 1, t + 2, t + 3$. We report the regression results estimation of Equation (3.1) in Table 3.3. Columns (1)-(4) show the regression result for the manufacturer's Revenue in years t to $t + 3$. The coefficient estimates on *Ride hailing Revenue* are all positive but they are statistically significant from time $t + 1$ to $t + 3$, suggesting the ride-hailing growth has a lead effect on manufacturer's profitability. It shows the positive effect of the emerging and growth of ride-hailing on the manufacturer's profitability happens only in the next three years. The results of Table 3.3 provide strong support for Hypothesis 1 and it is consistent with the findings of Jiang and Tian (2018). It shows that the enhancement effect dominates the cannibalization effect. Also, some of the control variables are significant. Specifically, manufacturer's ability to being an acquirer, and GDP are shown to positively affect the level of manufacturer's profitability.

Table 3.3: Baseline Regression Results for Hypothesis 1. *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively

Variable	t	$t + 1$	$t + 2$	$t + 3$
Ride-hailing Revenue	0.011 (0.009)	0.026*** (0.008)	0.025*** (0.007)	0.026*** (0.006)
Cash	-2.405*** (0.782)	-2.405*** (0.895)	-1.304* (0.657)	-0.330 (0.421)
Cumulative Active M&A	245.838* (124.90)	263.132** (126.38)	238.514** (113.785)	204.538* (101.794)
HHI	0.090 (0.100)	-0.274*** (0.086)	-0.364*** (0.078)	-0.062 (0.0807)
GDP	1.671*** (0.787)	1.613*** (0.768)	1.405* (0.760)	0.448 (0.863)
Car to Trips	0.380 (0.838)	1.370* (0.753)	1.363* (0.760)	-0.0308 (0.903)
R-squared overall	0.492	0.5044	0.502	0.502

Conversely, manufacturer tendency to spend money rather than investing and industry concentration have a negative influence on profitability.

To test Hypothesis 2, we construct two models to identify the effect of ride-hailing on innovation input and innovation output. In Model 3.2, we construct a basic linear model to investigate the impact of ride-hailing growth on innovation input which is R&D. We include all independent and control variables in Hypothesis 1 in this model. We apply the fixed-effect method to find the causality effect of ride-hailing revenue on innovation input.

$$R\&D_{it} = \beta_1 Cash_{it} + \beta_2 CumulativeActiveM\&A_{it} + \beta_3 RidehailingRevenue_t + \beta_4 HHI_{jt} + \beta_5 GDP_t + \beta_6 CartoTrips_t + c_i + u_{it}, \quad t = 1, \dots, T \quad (3.2)$$

In Model 3.3, we investigate the impact of ride-hailing on innovation output. We use the number of granted patents as an indicator to measure the innovation output. Since the number of granted patents takes only non-negative integers values, the linear regression model is inappropriate. The linear regression model assumes that the residual is normally distributed and is homoscedastic. However, when the dependent variable is a count variable- a variable takes only non-negative integer value-, these assumptions cannot be held. Using linear regression in this situation could lead to biased and inconsistent coefficient estimation (Greene, 2000). The negative binomial regression is the more appropriate model for the count data (Bellamy et al., 2014). Therefore, we develop Model 3.3 and apply the fixed-effect negative-binomial method to find the causality effect of ride-hailing revenue on innovation output. Since the direct positive effect of R&D expenditure on innovation output has been approved empirically in previous studies, we control for R&D expenditure by introducing R&D intensity which is yearly R&D expenditure scaled by asset in Model 3.3 to isolate its effect on innovation output.

$$\begin{aligned}
Patents_{it} = & \beta_1 R\&DIntensity_{it} + \beta_2 Cash_{it} + \beta_3 CumulativeActiveM\&A_{it} + \\
& \beta_4 RidehailingRevenue_t + \beta_5 HHI_{jt} + \beta_6 GDP_t + \beta_7 CartoTrips_t + c_i + u_{it}, \quad t = 1, \dots, T
\end{aligned}
\tag{3.3}$$

The dependent variables in models 2 and 3 are our measure of innovation input (R&D), and innovation output (number of granted patents), measured at time $\tau = t + 1, t + 2, t + 3$. We report the results estimation of equations 3.2 and 3.3 in tables 3.4 and 3.5. Columns (1)-(3) in Table 3.4 show the regression results for innovation input, *R&D*, in years $t + 1$ to $t + 3$. The coefficient estimates on *Ride-hailing Revenue* are all positive and significant, suggesting the level of innovation input increased with an increase in ride-hailing market revenue. The results in columns (2) and (3) suggest that the effects extends to R&D expenditure in the next two years ($p < 0.05$).

Columns (1)-(3) in Table 3.5 show the negative binomial regression results for innovation output, *number of granted patents*, in years $t + 1$ to $t + 3$. The coefficient estimates on *Ride-hailing Revenue* are again all positive and significant, suggesting the level of innovation output increased with an increase in ride-hailing market revenue. Thus, the results of models 3.2 and 3.3 provide strong support for Hypothesis 2.

To test Hypothesis 3, we construct two models to identify the influence of manufacturer's profitability (i.e., *Revenue*) on the relationship between the dependent variable (i.e., *Ride-hailing Revenue*), and independent variables which are *R&D* and *number of granted patents*. In Hypothesis 3, we want to make clear the causal pathway of the effect of ride-hailing growth on innovation. This hypothesis tells us how or why this effect takes place. To test Hypothesis 3 we use mediation analysis. Mediation analysis tests a hypothetical causal chain where an independent variable affects another variable, the mediator variable, and that variable affects the dependent variable (Lange et al., 2017). In this hypothesis, by using linear regression analysis we want to test whether *Revenue* variable is a mediator variable. If the change in

Table 3.4: Baseline Regression Results for Hypothesis 2, Model 3.2 . *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively

Variable	$t + 1$	$t + 2$	$t + 3$
Ride-hailing Revenue	0.022* (0.013)	0.021** (0.010)	0.021** (0.008)
Cash	-0.507 (0.871)	-0.159 (0.739)	-0.129 (0.17)
Cumulative Active M&A	222.285* (114.743)	213.743** (102.988)	178.441* (96.424)
HHI	-0.094 (0.087)	-0.179** (0.089)	-0.069 (0.094)
GDP	1.075 (0.700)	0.707 (0.760)	0.108 (0.979)
Car to Trips	0.555 (0.741)	0.367 (0.704)	-0.335 (0.982)
R-squared overall	0.472	0.479	0.481

Table 3.5: Baseline Regression Results for Hypothesis 2, Model 3.3 . *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively

Variable	$t + 1$	$t + 2$	$t + 3$
Ride-hailing Revenue	0.036** (0.016)	0.034** (0.016)	0.035** (0.016)
R&D intensity	0.369 (2.138)	-0.218 (2.367)	-0.159 (2.439)
Cash	-2.241** (1.184)	-1.189 (1.207)	-2.095* (1.233)
Cumulative Active M&A	71.342*** (27.588)	80.280*** (28.943)	85.068*** (30.526)
HHI	-0.272 (0.278)	0.039 (0.089)	-0.276 (0.229)
GDP	0.309 (1.121)	-0.029 (1.035)	-1.469 (1.760)
Car to Trips	1.246 (1.190)	0.155 (0.704)	-0.934 (1.699)
Log Likelihood	-1736.851	-1594.756	-1446.076

the level of the dependent variable significantly accounts for variation in the *Revenue* variable, then the variable is considered a mediator variable.

There are two types of mediation: full mediation and partial mediation (Nitzl et al., 2016). Full mediation is the case in which the mediator variable fully explains the relationship between the independent variable and the dependent variable. In our problem, if full mediation exists, then the independent variable (i.e., *Ride-hailing Revenue*) no longer affects the dependent variable (i.e., Innovation) after controlling for the *Revenue* variable. Full mediation makes the path “*b*” in Figure 3.1 zero. However, in partial mediation, the independent variable still affects the dependent variable, but its effect has been significantly reduced after controlling for the mediator variable. In partial mediation, the path “*b*” in Figure 3.1 is reduced in absolute size but is still different from zero.

In this case, we use Baron & Kenny method to describe the mediation effect (Baron and Kenny, 1986). The Baron and Kenny method is an analysis strategy for testing mediation hypotheses. This method has three steps as follows:

- Step1: Estimate the effect of the independent variable (X) on the dependent variable (Y) (i.e., models 3.2, 3.3). Path “*b*” must be significantly different from 0 in Figure 3.1
- Step2: Estimate the effect of the independent variable (X) on the mediator variable (M) (i.e., Model 3.1). Path “*a*” must be significantly different from 0 in Figure 3.1
- Step3: Estimate the effect of the dependent variable (X) on the independent variable (Y) after controlling for the mediator variable (M) (i.e, models 3.4). We want variable M affects variable Y, but variable X to no longer affect variable Y (or X still affect Y but in a smaller magnitude).

We construct two models to test the mediation effect of revenue on innovation. In models 3.4 and 3.5, we investigate whether variable *Revenue* partially mediates the

effect of *Ride-hailing Revenue* on *R&D* and *number of granted patents* by adding variable *Revenue* to the right-hand side of models 3.2 and 3.3, respectively.

$$\begin{aligned}
R\&D_{i\tau} = & \beta_1 Cash_{it} + \beta_2 CumulativeActiveM\&A_{it} + \beta_3 Revenue_{it} + \\
& \beta_4 RidehailingRevenue_t + \beta_5 HHI_{jt} + \beta_6 GDP_t + \beta_7 CartoTrips_t + c_i + u_{it}, \quad t = 1, \dots, T
\end{aligned} \tag{3.4}$$

$$\begin{aligned}
Patents_{i\tau} = & \beta_1 R\&Dintensity_{it} + \beta_2 Cash_{it} + \beta_3 CumulativeActiveM\&A_{it} + \\
& \beta_4 Revenue_{it} + \beta_5 RidehailingRevenue_t + \beta_6 HHI_{jt} + \beta_7 GDP_t + \beta_8 CartoTrips_t + \\
& c_i + u_{it}, \quad t = 1, \dots, T
\end{aligned} \tag{3.5}$$

The dependent variables in models 3.4 and and innovation output, measured at time $\tau = t + 1, t + 2, t + 3$. In these two models, we estimate the relationship between ride-hailing growth and innovation after controlling for the mediator variable. We consider this variable as an indicator of manufacturer's profitability. We report the results estimation of equations 3.4 and 3.5 in tables 3.6 and 3.7.

Columns (1)-(3) in Table 3.6 show the regression results for innovation input (i.e., *R&D expenditure*) by controlling the mediator variable, *Revenue*. The coefficient estimates on variable *Revenue* are all positive and statistically significant suggesting that the level of innovation input increased with an increase in the manufacturer's revenue. Also, the coefficient estimator on *Ride-hailing Revenue* is not statistically significant at time $t + 1$ suggesting that the manufacturer's revenue fully mediates between variable Ride-hailing revenue and R&D expenditure. In other words, the relationship between the Ride-hailing revenue and the R&D variable no longer exists, and their variations are controlled by the manufacturer's revenue as the mediator variable. However, the coefficient of ride-hailing at times $t + 2$ and $t + 3$ are all positive and significant, but they are smaller than those in Model 3.2. The observed results suggest that the manufacturer's revenue as a proxy for the manufacturer's

profitability does partially mediate the relationship between ride-hailing growth and innovation input which supports Hypothesis 3. When the mediation effect presents in a model, the total effect of the independent variable can be broken into two parts: the direct and indirect effects. The direct effect is the effect of the independent variable on the dependent variable in the absence of the mediator variable. The indirect effect is the effect of the independent variable on the dependent variable that works through the mediator variable. Therefore, the results of models 3.2 and 3.4 suggest that ride-hailing growth has both direct and indirect impact on innovation input at times $t + 2$ and $t + 3$. But it has only a direct impact at time $t + 1$.

Columns (1)-(3) in Table 3.7 show the negative binomial regression results for innovation output, *number of granted patents* by controlling the variable, *Revenue*. The coefficient estimates on *Revenue* are not statistically significant and the coefficient estimator on *Ride-hailing Revenue* are all positive and significant from time $t + 1$ to $t + 3$ and they are the same as those in Model 3.3. The observed results suggest that manufacturer's revenue which is a proxy for manufacturer's profitability does not mediate the relationship between ride-hailing revenue and innovation output (i.e., number of granted patent). Therefore, ride-hailing revenue has only a direct effect on innovation output. The results of this analysis dose not support Hypothesis 3 for innovation output.

3.5 Robustness test

Next, we consider a set of tests to establish the robustness of the results.

Heteroskedasticity. Heteroskedasticity refers to the case where the variance of the error term is not constant across the observations. This problem leads to a less efficient estimator. To check the presence of heteroskedasticity, We plotted the scatter plot of the standardized residuals vs. standardized predicted values. The plot shows our data sufferers from this problem. To address this issue, we applied a heteroskedasticity-robust standard error.

Table 3.6: Baseline Regression Results for Hypothesis 3, Model 3.4 . *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively

Variable	$t + 1$	$t + 2$	$t + 3$
Ride-hailing Revenue	0.013 (0.009)	0.015** (0.007)	0.016** (0.007)
Revenue	0.608*** (0.087)	0.595*** (0.097)	0.564*** (0.126)
Cash	1.031* (0.542)	1.324*** (0.481)	1.333*** (0.377)
Cumulative Active M&A	69.206 (61.470)	62.563 (54.416)	31.693 (56.643)
HHI	-0.147 (0.091)	-0.268*** (0.084)	-0.167*** (0.094)
GDP	0.163 (0.515)	-0.001 (0.663)	-0.260 (0.923)
Car to Trips	0.420 (0.493)	0.578 (0.509)	0.233 (0.839)
R-squared overall	0.890	0.890	0.884

Table 3.7: Baseline Regression Results for Hypothesis 3, Model 3.5 . *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively

Variable	$t + 1$	$t + 2$	$t + 3$
Ride-hailing Revenue	0.036** (0.016)	0.034** (0.016)	0.035** (0.016)
Revenue	0.036** (0.016)	0.034** (0.016)	0.035** (0.016)
R&D intensity	0.369 (2.138)	-0.218 (2.367)	-0.159 (2.439)
Cash	-2.241** (1.184)	-1.189 (1.207)	-2.095* (1.233)
Cumulative Active M&A	71.342*** (27.588)	80.280*** (28.943)	85.068*** (30.526)
HHI	-0.272 (0.278)	0.039 (0.089)	-0.276 (0.229)
GDP	0.309 (1.121)	-0.029 (1.035)	-1.469 (1.760)
Car to Trips	1.246 (1.190)	0.155 (0.704)	-0.934 (1.699)
Log Likelihood	-1736.851	-1594.756	-1446.076

Serial correlation. Serial correlation is where the error term in one period is correlated to the error term in the next period. Serial correlation invalidates the usual standard error formulas produces biased coefficients in regression analysis, leading to unreliable hypothesis testing. We used the Wooldridge test to check the presence of serial correlation in our panel data set. The result of the test shows that serial correlation is a problem in our data. To address this issue we used clustering standard error at the manufacturer level. This approach is most effective way when the panel data has large N and small T (Gong et al., 2017). There are 19 years and 42 manufacturers in our data. This method allows for serial correlation errors within an entity.

Multicollinearity. To ensure that results are not sensitive to the correlation among variables, we examined the variation inflation factor (VIF) test among all variables. All the VIF values generated are well below 10, which demonstrates that multicollinearity is not a major issue in our study.

3.6 Discussion and Conclusion

In this study, we examined the effect of ride-hailing platforms emergence and growth on auto manufacturers' profitability and innovation. Sharing platforms enable product sharing among owners with underutilized resources and consumers with temporary needs. Since ride-hailing platforms entry have both negative impact (i.e., cannibalization effect) and positive impact (i.e., enhancement effect), the effect of the emergence and growth of these platforms on manufacturer's profit and innovation is not clear. Motivated by this, our study offers insight for the manufacturers regarding the effect of ride-hailing on profit and innovation. Our research empirically investigates the effect of the ride-hailing platform on manufacturers' profit and innovation input and output. Also, it explains the relationship between ride-hailing platforms and innovation in the united States.

Our data set contains all auto manufacturers and auto part manufacturers from 2000 to 2019 that can be found in the Compustat database. We use R&D expenditures and the number of granted patents as indicators of innovation. To measure the emergence and growth of the ride-hailing business model, we consider the annual revenue of Uber and Lyft in the United States as an indicator. Finally, we apply the fixed-effect model to find the causality effect of ride-hailing on manufacturers' profitability and innovation. Also, we apply mediation analysis to explain the mechanism that underlies the relationship between ride-hailing and innovation.

Our findings suggest that the emergence and growth of ride-hailing platforms positively impact manufacturers' profitability. One plausible explanation for this effect is that the value-enhancement effect dominates the cannibalization effect. The other explanation for this effect is that auto manufacturers increase the sales price in the presence of ride-hailing platforms. This is explained by consumers willingness to pay a higher price to purchase the product because the product can be a moneymaker for them.

Also, our study offers empirical evidence that ride-hailing platform emergence and growth positively impact manufacturers' innovation. By mediation analysis, we reveal the underlying mechanism between ride-hailing and innovation input. The results show that manufacturers' profitability partially mediates the relationship between ride-hailing and innovation input. It means ride-hailing has both a direct effect and an indirect effect on innovation input. The plausible reasoning for the direct effect of ride-hailing on innovation is that, under the presence of ride-hailing platforms, the consumers' willingness to pay a higher selling price may increase since they anticipate obtaining extra revenue through the ride-hailing platform. This gives an incentive to the manufacturer to be more innovative. The reasoning for the indirect impact of ride-hailing on innovation input is that ride-hailing increases manufacturers' profitability, as a result, the manufacturer can invest more money in research and development.

Our results offer remarkable implications for both theory and practice. From a theoretical perspective, according to our knowledge, previous literature discusses

only the impact of peer-to-peer product sharing on manufacturers' profitability, and these researchers consider the "value enhancement effect" and "cannibalization effect" as mutually exclusive. However, our study investigates impact of both of them on manufacturers' profitability. Also, this study is the first, to our knowledge, to provide empirical evidence of the impact of product sharing on innovation.

As for practice, our results offer important insights for manufacturers, managers of on-demand product sharing platforms, and policy makers. First, these results suggest that manufacturers benefit from the presence of ride-hailing platforms. Therefore, auto manufacturer should advocate the emergence and growth of ride-hailing platforms. Also, ride-hailing platforms may collaborate with auto manufacturers to produce vehicles that are more appropriate for this business model.

There are several avenues of further research that can originate from our work. We can conduct another empirical study to find the underlying mechanism between ride-hailing growth and manufacturers' profitability. Also, we can find instrumental variables to control the effect of unobserved confounding variables which have effect on both independent variables and dependent variable.

Chapter 4

Conclusions

In this dissertation we investigate the effect of sharing economy business model on economic, environment, and innovation. In particular, we study the impact of peer-to-peer sharing economy on economic and environment, and on-demand sharing economy on innovation and manufacturers' profitability.

In Chapter 2, we develop a game-theoretic model to study the impact of peer-to-peer product sharing on manufacturers' profitability and environment. The model involves three players: the manufacturer, the sharing platform, and the consumers. Our research finds the conditions that enable the peer-to-peer sharing economy and determines whether this business model can be both more profitable to the manufacturer and environmentally superior as compared to other consumption models such as pure sales and servicizing.

Our study finds where the manufacturer only sells the product, the peer-to-peer sharing economy emerges as a unique equilibrium if the heterogeneity in product usage needs between low and high-segment consumers is sufficiently high, or the portion of high-segment consumers is neither too low nor too high. Also, comparing the peer-to-peer sharing economy model with pure sales and servicizing allows us to derive several important results. First, the manufacturer always produces more efficient products under sharing economy than in the pure sales model; however, it prefers

to produce more efficient products under sharing economy than servicing only if the degree of pooling is sufficiently low. Importantly, we find that the peer-to-peer sharing economy can be a win-win strategy wherein it can simultaneously increase a manufacturer’s profits and decrease its environmental impact, as compared to pure sales and servicing business models.

In Chapter 3, we conduct empirical research to investigate the effect of the emergence and growth of ride-hailing, which is a prominent example of the “on-demand sharing economy” on manufacturers’ profitability and innovation in the auto industry. To measure innovation, we use the research and development expenditure and the number of patents granted to each manufacturer from 2000 to 2019. To measure the profitability, we use the manufacturer’s annual revenue. The emergence of ride-hailing and its growth are measured based on the annual revenue of the two main companies operating in this area, Uber and Lyft. We consider manufacturer’s and industry characteristics and economic conditions as control variables. We applied fixed-effect to find the causal effect of ride-hailing emergence and growth on profitability and innovation. Also, we use mediation analysis to find the underlying mechanism in the relationship between ride-hailing and innovation.

The empirical results show that ride-hailing growth has a significant positive impact on both manufacturers’ profitability and innovation. Also, our study finds that manufacturers’ profitability partially mediates the relationship between ride-hailing and innovation input. The result of this research suggests that manufacturers in the auto industry should advocate the presence and growth of ride-hailing platforms since they obtain more profit and become more innovative.

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Appendix A

Summary of Equations

A.1 Proof of Lemma 1.

There are two cases, the first where only the high-segment consumers ($i = H$), and the second where only the low-segment consumers ($i = L$) purchase the product.

Let's start with the first case, where only the high-segment consumers purchase the product. After the purchase, a high-segment consumer's optimal product usage in case of sharing and non sharing is given by τ_{Hs}^{o*} and τ_{Hn}^{o*} , respectively, as follows:

$$\tau_{Hs}^{o*} = \underset{\tau \geq 0}{U_{Hs}^o}(\tau) = 1 - \varphi w - k(1 - e) \quad (\text{A.1})$$

$$\tau_{Hn}^{o*} = \underset{\tau \geq 0}{U_{Hn}^o}(\tau) = 1 - k(1 - e). \quad (\text{A.2})$$

If a low-segment consumer rents the product, her optimal usage is given by τ_{Ls}^{r*} as follows:

$$\tau_{Ls}^{r*} = \underset{\tau \geq 0}{U_{Ls}^r}(\tau) = \alpha - w - k(1 - e). \quad (\text{A.3})$$

The rental fee, w , is selected to clear the market. In particular, as the high-segment consumers purchase the product it follows that $M^o = \beta M$ and $M^r = (1 - \beta)M$. Then, we solve (2.4) for w and obtain: $w^* = \frac{\alpha(1-\beta)-k(1-e)}{1-\beta(1-\varphi)}$.

Next, the platform selects φ by solving problem (2.5) for $i = H$, which is reported again below for convenience:

$$\begin{aligned}
\max_{\varphi} \quad & \Pi_l = (1 - \varphi)w^*\beta M(1 - \tau_{Hs}^{o*}) \\
\text{s.t.} \quad & U_{Hs}^o(\tau_{Hs}^{o*}, w^*, \varphi) \geq U_{Hn}^o(\tau_{Hn}^{o*}) \\
& U_{Ls}^r(\tau_{Ls}^{r*}, w^*) \geq 0 \\
& 0 \leq \varphi \leq 1 \\
& \tau_{Ls}^{r*}, \tau_{Hs}^{o*} \geq 0.
\end{aligned} \tag{A.4}$$

The first two constraints in problem (A.4) can be rewritten as follows: 1) $U_{Hs}^o(\tau_{Hs}^{o*}, w^*, \varphi) - U_{Hn}^o(\tau_{Hn}^{o*}) = \varphi w^* \left[\frac{\varphi w^*}{2} + k(1 - e) \right] \geq 0$, and 2) $U_{Ls}^r(\tau_{Ls}^{r*}, w^*) = \frac{[w^* - \alpha + k(1 - e)]^2}{2} \geq 0$, which are always verified. Then, considering the expressions of optimal product usage in (A.1) and (A.3), the last constraints in problem (A.4) can be rewritten as follows: 3) $\tau_{Ls}^{r*} = \frac{(1 - \varphi)(1 - e)k + \alpha\varphi}{1 - \beta(1 - \varphi)} \geq 0$, which is always verified, and 4) $\tau_{Hs}^{o*} = 1 - \frac{(1 - \beta)[(1 - e)(1 - \varphi)k + \alpha\varphi]}{1 - \beta(1 - \varphi)} \geq 0$. Since $\tau_{Ls}^{r*} < \tau_{Hs}^{o*}$, it follows that constraint 4) is also verified. Then, problem (A.4) can be written as follows:

$$\begin{aligned}
\max_{\varphi} \quad & \Pi_l = (1 - \varphi)w^*\beta M(1 - \tau_{Hs}^{o*}) \\
\text{s.t.} \quad & 0 \leq \varphi \leq 1.
\end{aligned} \tag{A.5}$$

The interior solution is given by $\varphi^* = \frac{N(e)}{D(e)} = \frac{2k(1 - e) - \alpha(1 - \beta)}{2k(1 - e) - \alpha(2 - \beta)}$, where $N(e)$ and $D(e)$ denote the numerator and the denominator of φ^* , respectively. Given that $N(e) > D(e)$, the constraint $0 \leq \varphi^* \leq 1$ implies $N(e) \leq 0$, which in turn implies $e \geq 1 - \frac{\alpha(1 - \beta)}{2k}$.

Let's move to the second case now, where only the low-segment consumers purchase the product. After the purchase, a low-segment consumer's optimal product usage in case of sharing and non sharing is given by τ_{Ls}^{o*} and τ_{Ln}^{o*} , respectively, as

follows:

$$\tau_{Ls}^{o*} = \underset{\tau \geq 0}{U_{Ls}^o(\tau)} = \alpha - \varphi w - k(1 - e) \quad (\text{A.6})$$

$$\tau_{Ln}^{o*} = \underset{\tau \geq 0}{U_{Ln}^o(\tau)} = \alpha - k(1 - e). \quad (\text{A.7})$$

If the high-segment consumer rents the product, her optimal usage is given by τ_{Hs}^{r*} as follows:

$$\tau_{Hs}^{r*} = \underset{\tau \geq 0}{U_{Hs}^r(\tau)} = 1 - w - k(1 - e). \quad (\text{A.8})$$

The rental fee, w , is selected to clear the market. In particular, as the low-segment consumers purchase the product it follows that $M^o = (1 - \beta)M$ and $M^r = \beta M$. Then, we solve (2.4) for w and obtain: $w^* = \frac{(2-\alpha)\beta + \alpha - k(1-e) - 1}{\varphi + (1-\varphi)\beta}$.

Next, the platform selects φ by solving problem (2.5) for $i = L$, which is reported below for convenience:

$$\begin{aligned} \max_{\varphi} \quad & \Pi_l = (1 - \varphi)w^*(1 - \beta)M(1 - \tau_{Ls}^{o*}) \\ \text{s.t.} \quad & U_{Ls}^o(\tau_{Ls}^{o*}, w^*, \varphi) \geq U_{Ln}^o(\tau_{Ln}^{o*}) \\ & U_{Hs}^r(\tau_{Hs}^{r*}, w^*) \geq 0 \\ & 0 \leq \varphi \leq 1 \\ & \tau_{Ls}^{o*}, \tau_{Hs}^{r*} \geq 0. \end{aligned} \quad (\text{A.9})$$

The first two constraints in problem (A.9) can be rewritten as follows: 1) $U_{Ls}^o(\tau_{Ls}^{o*}, w^*, \varphi) - U_{Ln}^o(\tau_{Ln}^{o*}) = \varphi w^* \left[\frac{\varphi w^*}{2} + (1 - \alpha) + k(1 - e) \right] \geq 0$, and 2) $U_{Hs}^r(\tau_{Hs}^{r*}, w^*) = \frac{[1 - w^* - k(1 - e)]^2}{2} \geq 0$, which are always verified. Then, considering the expressions of optimal product usage in (A.6) – (A.8), the last constraint of problem (A.9) can be rewritten as follows: 3) $\tau_{Ls}^{o*} = \frac{[(1-e)k-2]\varphi - k(1-e) + \alpha}{\varphi + (1-\varphi)\beta} \geq 0$, and 4) $\tau_{Hs}^{r*} = \frac{(1-\beta)[(1-(1-e)k)\varphi - \alpha + 1 + k(1-e)]}{\varphi + (1-\varphi)\beta} \geq 0$. Since $\tau_{Ls}^{o*} < \tau_{Hs}^{r*}$, then problem (A.9) can be written

as follows:

$$\begin{aligned}
\max_{\varphi} \quad & \Pi_l = (1 - \varphi)w^*(1 - \beta)M(1 - \tau_{Ls}^{o*}) \\
s.t. \quad & 0 \leq \varphi \leq 1 \\
& \tau_{Ls}^{o*} \geq 0.
\end{aligned} \tag{A.10}$$

The interior solution of (A.10) is given by $\varphi^* = \frac{N(e)}{D(e)} = \frac{2k(1-e)-\alpha(2-\beta)+2(1-\beta)}{2k(1-e)-\alpha(1-\beta)-2\beta}$, where $N(e)$ and $D(e)$ denote numerator and denominator of φ^* , respectively. Given $N(e) > D(e)$, the constraint $0 \leq \varphi^* \leq 1$ implies $N(e) \leq 0$, which in turn implies $e \geq 1 - \frac{\alpha(2-\beta)-2(1-\beta)}{2k}$. Also, by substituting φ^* , the last constraint of problem (A.10) can be written as $1 - \beta(1 - \frac{1}{2}\alpha) \geq 0$ which is always verified.

Proof of Lemma 2. Assume the low-segment consumers purchase the product. Then, there are two cases: the first where the product is shared and the second where the product is not shared.

1. **Product is shared.** The product purchased by the low-segment consumer can be shared only if the following incentive-compatibility constraints are satisfied:

$$U_{Ls}^o(\tau_{Ls}^{o*}, w^*, \varphi^*) \geq U_{Ls}^r(\tau_{Ls}^{r*}, w^*) \tag{A.11}$$

$$U_{Hs}^r(\tau_{Hs}^{r*}, w^*) \geq U_{Hs}^o(\tau_{Hs}^{o*}, w^*, \varphi^*), \tag{A.12}$$

where (A.11) requires that the low-segment consumer prefers purchasing the product rather than renting it, whereas (A.12) requires that the high-segment consumer has the opposite preference. Constraints (A.11) and (A.12) imply $p \in [p^{lb}, p^{ub}]$, where $p^{ub} = \beta(\frac{\alpha}{2} - \frac{\alpha^2}{4}) - k(1 - e) + \alpha - \frac{\alpha^2}{8} - \frac{1}{2}$ and $p^{lb} = \beta(\frac{\alpha}{2} - \frac{\alpha^2}{4}) - k(1 - e) - \frac{\alpha}{2} + \frac{3\alpha^2}{8} + \frac{1}{2}$. Given that $0 \leq \alpha \leq 1$, it follows $p^{ub} \leq p^{lb}$, which implies that the system of inequalities (A.11) and (A.12) yields no solution. Thus, it is never possible that the low-segment consumer purchases the product and shares it with the high-segment consumer.

2. **Product is not shared.** The utility of the low-segment consumer when she purchases and uses the product, without sharing it, is given by $U_{Ln}^o(\tau^*) =$

$\frac{[(1-e)k]^2 + \alpha^2}{2} - \alpha(1-e)k - p$, which is positive for p sufficiently low. However, regardless of the price, $U_{Hn}^o(\tau^*) - U_{Ln}^o(\tau^*) = \frac{(1-\alpha)[1+\alpha-2k(1-e)]}{2} \geq 0$, which implies the high-segment consumer will purchase and use the product as well.

A.2 Proof of Proposition 1.

According to Lemma 2 there are two cases, the first where only high segment consumers purchase the product (case 1), and the second where both high and low segments purchase the product (case 2).

We first examine case 1), which is the only case where sharing economy can arise. The problem that the firm needs to solve is reported in (2.7) and includes the two following incentive-compatibility constraints: $U_{Hs}^o(\tau_{Hs}^{o*}, w^*) \geq U_{Hs}^r(\tau_{Hs}^{r*}, w^*)$, and $U_{Ls}^r(\tau_{Ls}^{r*}, w^*) \geq U_{Ls}^o(\tau_{Ls}^{o*}, w^*)$, where the first inequality requires that high type consumers prefer purchasing than renting the product, whereas the second inequality implies the opposite preference for low type consumers. The two incentive-compatibility constraints are linear in price p and can be written as $p \in [p^{lb}, p^{ub}]$, where $p^{ub} = \alpha - k(1-e) - \frac{3\alpha^2}{8} - \frac{\alpha\beta}{2}(1 - \frac{\alpha}{2})$, and $p^{lb} = \frac{\alpha}{2} - k(1-e) + \frac{\alpha^2}{8} - \frac{\alpha\beta}{2}(1 - \frac{\alpha}{2})$. It is verified that $p^{ub} \geq p^{lb} \geq 0$. Then, the firm at time 1 (see the sequence of events reported in Figure 2.1) selects price and efficiency by solving the following problem:

$$\begin{aligned} \max_{p,e} \quad & \Pi_f^{sh} = \beta M(p - ce^2) \\ \text{s.t.} \quad & p^{lb} \leq p \leq p^{ub} \\ & 1 - \frac{\alpha(1-\beta)}{2k} \leq e < 1, \end{aligned} \tag{A.13}$$

which is the same problem as (2.7), but with the incentive-compatibility constraints substituted by the inequalities in p . The KKT conditions provide the two following solutions. The first solution is binding both in price and efficiency, and occurs for $k \leq 2c$ and $\alpha c(1-\beta) \leq k(2c-k)$. The solution is given by $\{e^{*sh} = 1 - \frac{\alpha(1-\beta)}{2k}, p^{*sh} = p^{ub}(e^{*sh}) = \frac{\alpha}{2} - \frac{(3-2\beta)\alpha^2}{8}\}$ and yields firm profit $\Pi_f^{*sh} =$

$\left[\left(\frac{(2k-\alpha+\alpha\beta)^2}{4} \right) c + \frac{(3\alpha-2\alpha\beta-4)\alpha k^2}{8} \right] \frac{M\beta}{k^2}$. This is an extreme case, where the platform will select $\varphi^* = 0$, i.e., owners will be indifferent between sharing and not sharing their product. The second solution is binding in price and interior in efficiency, and occurs for $k \leq 2c$ and $\alpha c(1 - \beta) \geq k(2c - k)$. The solution is given by $\{e^{*sh} = \frac{k}{2c}, p^{*sh} = p^{ub}(e^{*sh}) = \frac{(8\alpha-8k-3\alpha^2)c+4k^2}{8c} - \frac{\alpha\beta}{2}(1 - \frac{\alpha}{2})\}$ and yields firm profit $\pi^{*sh} = \frac{1}{2}\alpha(\frac{\alpha}{2} - 1)\beta^2 - [(\frac{3\alpha^2}{8} - \alpha + k) - \frac{k^2}{4c}]\beta$. Next, we examine case 2), in which both high and low segments of consumers purchase the firm's product, and thus there is no product sharing. The firm solves the following problem:

$$\begin{aligned}
\max_{p,e} \quad & \Pi_f^{bb} = M(p - ce^2) \\
s.t. \quad & U_{Hn}^{o*}(\tau_{Hn}^{o*}) \geq 0 \\
& U_{Ln}^{o*}(\tau_{Ln}^{o*}) \geq 0 \\
& 0 < e < 1,
\end{aligned} \tag{A.14}$$

where the individual rationality constraints require that high and low segments have a non negative utility from buying the product. The solution to (A.14) is such that the second constraint is always binding, i.e., the firm extracts all the surplus from the low segment consumers. The KKT conditions provide the following solution. The solution occurs for $\alpha \geq k$ and $\alpha k \leq 2c$ and is given by $\{e^{*bb} = \frac{(\alpha-k)k}{2c-k^2}, p^{*bb} = \frac{2c^2(\alpha-k)^2}{(2c-k^2)^2}\}$ and yields firm profit $\Pi_f^{*bb} = \frac{Mc(\alpha-k)^2}{2c-k^2}$.

By comparing the sharing economy equilibrium with the buy/buy equilibrium, we determine two possible cases:

1. $\alpha \leq k$ and $k \leq 2c$, in which the firm attains negative profit under buy-buy, but positive profit under sharing economy,
2. $\alpha \geq k$ and $2c > k$.

In Case 2, sharing economy arises as the unique equilibrium if and only if $\Pi_f^{*sh} - \Pi_f^{*bb} \geq 0$. It turns out that this inequality is always quadratic concave in β ; thus, existence of its roots depends on the discriminant being positive. Below, we show the

detailed analysis for case 2. In this case, the inequality $\Pi_f^{*sh} - \Pi_f^{bb} \geq 0$ reduces to:

$$\frac{c\alpha}{4}(\alpha - 2)(2c - k^2)\beta^2 + [(\alpha - k - \frac{3}{8}\alpha^2)c + \frac{k^2}{4}](2c - k^2)\beta - (\alpha - k)^2c^2 \geq 0, \quad (\text{A.15})$$

which is concave in β , the associated equality has positive roots, β_{R_1} and β_{R_2} , iff $(\alpha - k - \frac{3}{8}\alpha^2)c + \frac{k^2}{4} \geq 0$ and the discriminant is positive, which is widely non-linear in α , k , and c .

A.3 Proof of Proposition 2.

Sharing economy may still arise as one of two possible equilibria if $p^{lb} \leq p^{*bb} \leq p^{ub}$ and $\pi^{*bb} \geq \pi^{*sh}$. As we proved, under condition 2 of Proposition 1, $\pi^{*bb} \geq \pi^{*sh}$ if $\beta < \beta_{R_1}$ or $\beta > \beta_{R_2}$. We solve $p^{lb} \leq p^{*bb} \leq p^{ub}$ under the case in which the firm attains positive profit under sharing economy and buy-buy. In this case the inequality $p^{lb} \leq p^{*bb}$ reduces to

$$\beta > \hat{\beta}_{R_1} = \frac{4(2k-\alpha)(2k-3\alpha+4)c^3 - 4(8k+4-\alpha^2-4\alpha)k^2c^2 + k^4(8k+16-\alpha^2-4\alpha)c - 4k^6}{2\alpha(2c-k^2)^2(\alpha-2)} \text{ and the inequality } p^{*bb} \leq p^{ub} \text{ reduces to}$$

$$\beta < \hat{\beta}_{R_2} = \frac{(16k^2 + (-32\alpha + 32)k + 28\alpha^2 - 32\alpha)c^3 - 4(3\alpha^2 + 8(k-\alpha) + 4)k^2c^2 + k^4(8k+16+3\alpha^2-8\alpha)c - 4k^6}{2\alpha(2c-k^2)^2(\alpha-2)}.$$

As a result, $p^{lb} \leq p^{*bb} \leq p^{ub}$ happens if $\hat{\beta}_{R_1} < \beta < \hat{\beta}_{R_2}$. It is clear that in all of the mentioned three cases $\hat{\beta}_{R_2} > \hat{\beta}_{R_1}$ and $\hat{\beta}_{R_2} > \beta_{R_2}$ and it is possible to have $\hat{\beta}_{R_1} \leq \beta_{R_1}$. Then, multi-equilibrium arises for $\beta \in [\hat{\beta}_{R_1}, \beta_{R_1}]$ and $\beta \in [\beta_{R_2}, \hat{\beta}_{R_2}]$.

There is no multi-equilibrium if $p^{lb} \leq p^{*bb} \leq p^{ub}$ and $\Pi^{*sh}(p = p^{*sh}) \leq \Pi^{*bb}(p = p^{lb})$. It is clear that $\Pi^{*bb}(p = p^{lb}) \leq \Pi^{*bb}(p = p^{*bb})$. The expression $\Pi^{*sh}(p = p^{*sh}) - \Pi^{*bb}(p = p^{lb}) \leq 0$ reduces to:

$$(2c\alpha^2 - 4c\alpha)\beta^2 + (-5c\alpha^2 + 12c\alpha - 8ck + 2k^2)\beta - c\alpha^2 - 4c\alpha + 8ck - 2k^2 \leq 0, \quad (\text{A.16})$$

which is a concave function in β and the inequality (A.16) is satisfied if $\beta < \dot{\beta}_{R1}$ or $\beta > \dot{\beta}_{R2}$. $\dot{\beta}_{R1}$ and $\dot{\beta}_{R2}$ are the associated equality of Expression (A.16) roots. Also, it is proved that $\dot{\beta}_{R1}$ and $\dot{\beta}_{R2}$ are always exist because the discriminant of expression A.16 is always positive. The discriminant of expression A.16 is reduced to:

$$(33\alpha^4 - 104\alpha^3 + (16k + 80)\alpha^2 - 64k\alpha + 64k^2)c^2 - 32\left(\frac{1}{8}\alpha^2 + k - \frac{1}{2}\alpha\right)k^2c + 4k^4, \quad (\text{A.17})$$

which is always positive. Since, $\Pi^{*bb}(p = p^{lb}) \leq \Pi^{*bb}(p = p^{*bb})$ for $p^{lb} \leq p^{*bb} \leq p^{ub}$, then it is clear that $\dot{\beta}_{R1} < \beta_{R1}$ and $\beta_{R2} < \dot{\beta}_{R2}$. Also, it is possible $\dot{\beta}_{R1}$ and $\dot{\beta}_{R2}$ are in the range of $[\hat{\beta}_{R1}, \hat{\beta}_{R2}]$. Therefore, for $\beta \in [\hat{\beta}_{R1}, \dot{\beta}_{R1}]$ and $\beta \in [\dot{\beta}_{R2}, \hat{\beta}_{R2}]$, multi-equilibrium cannot happen. As a result multi-equilibrium arises for restricted range of β which is $\beta \in [\dot{\beta}_{R1}, \beta_{R1}]$ and $\beta \in [\beta_{R2}, \dot{\beta}_{R2}]$.

A.4 Proof of Proposition 3.

Under a pure sales model, the manufacturer has the option to sell his product to both segments of consumers (i.e., buy-buy), or sell it to only high-segment consumers. The solution for buy-buy case is obtained by solving problem (??). However, when the manufacturer decides to sell his product to only high-segment consumers, it has to solve the following problem:

$$\begin{aligned} \max_{p,e} \quad & \Pi_f^{Hb} = \beta M(p - ce^2) \\ \text{s.t.} \quad & U_{Hn}^{o*}(\tau_{Hn}^{o*}) \geq 0 \\ & 0 < e < 1, \end{aligned} \quad (\text{A.18})$$

where the individual rationality constraint requires that high-segment consumers have a non-negative utility from buying the product. The solution to problem (A.18) is such that the first constraint is always binding, i.e., the manufacturer extracts all the surplus from the high-segment consumers. By KKT conditions, the solution occurs

if $k < \min\{1, 2c\}$, and is given by: $e^{*Hb} = \frac{(1-k)k}{2c-k^2}$, $p^{*Hb} = \frac{2c^2(1-k)^2}{(2c-k^2)}$, which yields the manufacturer's profit $\Pi_f^{*Hb} = \frac{M\beta c(1-k)^2}{2c-k^2}$.

The manufacturer prefers to sell the product to only high-segment consumers rather than both segments if and only if $\Pi_f^{*Hb} - \Pi_f^{bb} > 0$, which can be reduced to $\beta > \beta_{Hb} = \frac{(\alpha-k)^2}{(1-k)^2}$.

As we show in the proof of Proposition 1, the optimal efficiency under sharing economy and buy-buy are $e^{*sh} = \frac{k}{2c}$ and $e^{*bb} = \frac{(\alpha-k)k}{2c-k^2}$, respectively. Since $\alpha < 1$, it is clear that $e^{*Hb} > e^{*bb}$. Also, $e^{*sh} - e^{*Hb} = \frac{(2c-k)k^2}{2c(2c-k^2)}$ which is always positive. Then as a summary $e^{*sh} > e^{*Hb} > e^{*bb}$.

A.5 Proof of Proposition 4.

Under a pure sales model, the firm decides whether to sell the product to both segments of consumers or only to the high segment of consumers. In the first case, the solution corresponds to the buy/buy case analyzed in §2.3. In the second case, the firm has to solve the following problem:

$$\begin{aligned} \max_{p,e} \quad & \Pi_f^{Hb} = \beta M(p - ce^2) \\ \text{s.t.} \quad & U_{Hn}^{o*}(\tau_{Hn}^{o*}) \geq 0, \\ & 0 < e < 1, \end{aligned} \tag{A.19}$$

By KKT conditions, the solution occurs for the set of conditions where $k < \min\{1, 2c\}$, and is given by: $e^{*Hb} = \frac{(1-k)k}{2c-k^2}$, $p^{*Hb} = \frac{2c^2(1-k)^2}{(2c-k^2)}$, which yields the firm profit $\Pi_f^{*Hb} = \frac{M\beta c(1-k)^2}{2c-k^2}$.

The firm prefers the presence of the platform when $\Pi_f^{*sh} \geq \Pi_f^{*Hb}$. This inequality is evaluated for the following ranges of parameters:

1. $\alpha \leq k$, $k \leq 2c$, $k < 1$
2. $\alpha \geq k$, $k \leq 2c$.

Let's start with Case 1. As we discussed earlier for $k \leq 2c$, the optimal profit for problem (A.19) is $\Pi_f^{*Hb} = \frac{M\beta c(1-k)^2}{2c-k^2}$. Also, $\alpha \leq k$, $k \leq 2c$ implies $\alpha^2 \leq 2c$, as we show in proposition 1, firm obtains negative profit under buy-buy, but positive profit under sharing economy for this range of parameters. We compute the inequality $\Pi_f^{*sh} - \Pi_f^{*Hb} \geq 0$ which reduces to:

$$\begin{aligned} & \frac{1}{4}c(-k^2 + 2c)\alpha(\alpha - 2)\beta - \left[\left(k^2 - 2\alpha + 1 + \frac{3}{4}\alpha^2 \right) c - k^2 \left(k - \alpha + \frac{1}{2} + \frac{3}{8}\alpha^2 \right) \right] \\ & c - \frac{k^4}{4} \geq 0. \end{aligned} \tag{A.20}$$

The LHS of (A.20) is linear and has a negative slope with respect to β . As a consequence, (A.20) is satisfied for $\beta \leq \beta'_{R_1} = \frac{3c\alpha^2 k^2 - 6c^2\alpha^2 - 8c\alpha k^2 - 8c^2 k^2 + 8ck^3 - 2k^4 + 16c^2\alpha + 4ck^2 - 8c^2}{2(2-\alpha)(-k^2+2c)\alpha}$. One can easily show that if $\alpha \leq \frac{2}{3}$, then $\beta'_{R_1} \leq 0$. Let's move to Case 2, where the firm attains positive profit under buy-buy, sharing economy and high-buy. We restrict our analysis for the case where $\Pi_f^{*sh} - \Pi_f^{*bb} \geq 0$. The inequality $\Pi_f^{*sh} - \Pi_f^{*Hb} \geq 0$ is satisfied for $\beta \leq \beta'_{R_1}$. Under Case 2, the firm prefers the presence of a sharing platform if both $\Pi_f^{*sh} - \Pi_f^{*bb} \geq 0$ and $\Pi_f^{*sh} - \Pi_f^{*Hb} \geq 0$ are satisfied. These two inequality are satisfied if and only if $\beta \in [\beta_{R_1}, \beta'_{R_1}]$, where $\beta_{R_1} < \beta'_{R_1} < \beta_{R_2}$. The firm prefers selling the product to only high-segment rather than both segments if $\Pi_f^{*Hb} \geq \Pi_f^{*bb}$, which can be written as $\beta \geq \beta_{Hb} = \frac{(\alpha-k)^2}{(1-k)^2}$. $\Pi_f^{*sh} - \Pi_f^{*bb} \geq 0$ and $\Pi_f^{*sh} - \Pi_f^{*Hb} \geq 0$ are satisfied if and only if $\beta \in [\beta_{R_1}, \beta'_{R_1}]$, where $\beta_{R_1} < \beta_{Hb} < \beta'_{R_1} < \beta_{R_2}$.

A.6 Proof of Proposition 5.

The optimal efficiency under hybrid servicing by solving Model 2.10 is $e_{se}^{*h} = \frac{k(k-\alpha-\beta+\beta\alpha)}{2(\beta-2)(\gamma\beta-\gamma+1)c+k^2}$. The optimal efficiency under sharing economy is greater than that under hybrid servicing if and only if $e_{sh}^* - e_{se}^{*h} \geq 0$. We compute this inequality

which reduces to:

$$(\beta^2 - 3\beta + 2)c(1 - \gamma) + (-\beta^2 + (\alpha + 1)\beta + k - \alpha)c - \frac{k^2}{2} \geq 0. \quad (\text{A.21})$$

The LHS of inequality (A.21) is linear in $(1 - \gamma)$ with positive slope. Therefore, inequality (A.21) is satisfied for $1 - \gamma \geq \frac{2(\beta^2 - (\alpha + 1)\beta - k + \alpha)c + k^2}{\beta^2 - 3\beta + 2}$, which means $\gamma \leq \gamma_1^h = \frac{((2\alpha - 4)\beta + 2k - 2\alpha + 4)c - k^2}{(2\beta^2 - 6\beta + 4)c}$.

Also, the optimal efficiency under pure servicizing by solving Model 2.9 is $e_{se}^{*p} = \frac{k(\beta\alpha - \beta - \alpha + k)}{k^2 - 4c(1 - \gamma)}$. The optimal efficiency under sharing economy is greater than that under hybrid servicizing if and only if $e_{sh}^* - e_{se}^{*p} \geq 0$. We compute this inequality which reduces to:

$$(1 - \gamma)c + \frac{(k - (1 - \beta)\alpha - \beta)c}{2} - \frac{k^2}{4} \geq 0. \quad (\text{A.22})$$

The LHS of inequality (A.22) is linear in $(1 - \gamma)$ with positive slope. And one can easily show that the constant part is always negative. Therefore (A.22) is satisfied if $(1 - \gamma) \geq \frac{((-2\beta + 2)\alpha - 2k + 2\beta)c + k^2}{4c}$, which means $\gamma \leq \gamma_1^p = \frac{((2\beta - 2)\alpha + 2k - 2\beta + 4)c - k^2}{4c}$. One can easily show that $\gamma_1^p < 1 - \beta$, which shows that under this condition the number of products to meet consumers' needs under pure servicizing is higher than that under sharing economy. Therefore $e^{*sh} > \max\{e_{se}^{*h}, e_{se}^{*p}\}$ if $\gamma < \min\{\gamma_1^p, \gamma_1^h\} = \gamma_e^{se}$.

A.7 Proof of Proposition 6.

Under hybrid servicizing, the firm sells the product to the high-segment consumers and sells the usage of the product to the low-segment consumers. The optimal usage of high and low segment consumer is given by $\tau_{H,se}^{*h}$ and $\tau_{L,se}^{*h}$, respectively:

$$\tau_{H,se}^{*h} = \tau U_{H,se}^h(\tau) = 1 - k(1 - e) \quad (\text{A.23})$$

$$\tau_{L,se}^{*h} = \tau U_{L,se}^h(\tau) = \alpha - k(1 - e) - q \quad (\text{A.24})$$

The problem that the firm needs to solve is reported in (2.10) and include the two following incentive-compatibility constraints, where the first inequality requires the high-segment consumers prefer purchasing the product rather than purchasing the usage of the product, whereas the second inequality implies the low-segment consumers prefer to purchase the usage of the product rather than the product itself. The two incentive-compatibility constraints are linear in price p and can be written as $p \in [p^{lb}, p^{ub}]$, where $p^{ub} = \frac{q(2k(e-1)+2-q)}{2}$, and $p^{lb} = \frac{q(2k(e-1)+2\alpha-q)}{2}$. It is verified that $p^{ub} \geq p^{lb} \geq 0$. Then the firm selects selling price, pay per usage price and efficiency by solving the following problem:

$$\begin{aligned}
\max_{p,q,e} \quad & \Pi_{f,se}^h = (p - ce^2)M\beta + (q\tau_{L,se}^h - c(1 - \gamma)e^2)M(1 - \beta) \\
s.t. \quad & p^{lb} \leq p \leq p^{ub} \\
& q > 0 \\
& 0 < e < 1.
\end{aligned} \tag{A.25}$$

which is the same as (2.10), but with the incentive-compatibility constraints substituted by the inequalities in p . Since, problem (A.25) is increasing in p ; therefore, the optimal price, p_{se}^{*h} is equal to p^{ub} . The KKT conditions provide the following solution. The solution is given by $\{e_{se}^{*h} = \frac{k(k-\alpha-\beta+\beta\alpha)}{2(\beta-2)(\gamma\beta-\gamma+1)c+k^2}, q_{se}^{*h} = \frac{2((\alpha-1)\beta+k-\alpha)(\gamma\beta-\gamma+1)c}{2(\beta-2)(\gamma\beta-\gamma+1)c+k^2}\}$ and yields firm profit $\pi_{f,se}^{*h} = -\frac{(\gamma\beta-\gamma+1)c((\alpha-1)\beta+k-\alpha)^2 M}{2(\beta-2)(\gamma\beta-\gamma+1)c+k^2}$. The condition for $\pi_{f,se}^{*h} \geq 0$ is the following inequality:

$$2(\beta-2)(\gamma\beta-\gamma+1)c+k^2 \leq 0, \tag{A.26}$$

which is a linear function in c . The condition for $0 < e_{se}^{*h}$ and $0 < q_{se}^{*h}$ is the following inequality.

$$\alpha\beta - \alpha - \beta + k \leq 0, \tag{A.27}$$

The conditions for $e_{se}^{*h} < 1$ and $q_{se}^{*h} < q^{UB}$ are the following inequalities:

$$2(\beta - 2)(\gamma\beta - \gamma + 1)c - k((\alpha - 1)\beta - \alpha) \leq 0, \quad (\text{A.28})$$

$$-2(\gamma\beta - \gamma + 1)(\beta(k - 1) - k + \alpha)c + k^2\beta(\alpha - 1) \leq 0, \quad (\text{A.29})$$

One can easily show that both e_{se}^{*h} and q_{se}^{*h} are decreasing in γ . In order to compare hybrid servicizing with sharing economy, we focus only on the sets of parameters of Proposition 4. Sharing economy is more profitable than hybrid servicizing if and only if $\pi_f^{*sh} - \pi_{f,se}^{*h} \geq 0$. It turns out that this inequality is always linear in (γ) and it reduces to:

$$\begin{aligned} & c(1 - \beta) \left(\left[\left(\frac{1}{2}\alpha^2 - \alpha \right) \beta^3 + \left(-\frac{3}{4}\alpha^2 - 2k + 2\alpha + 1 \right) \beta^2 + \left(-\frac{\alpha^2}{2} + (2k - 2)\alpha + 2k \right) \beta + (k - \alpha)^2 \right] c + \frac{k^2}{2} \beta \right. \\ & (1 - \gamma) + \left(\left[\left(\frac{1}{2}\alpha^2 - \alpha \right) \beta^3 + \left(-\frac{3}{4}\alpha^2 - 2k + 2\alpha + 1 \right) \beta^2 + \left(-\frac{\alpha^2}{2} + (2k - 2)\alpha + 2k \right) \beta + (k - \alpha)^2 \right] c^2 + \right. \\ & \left. \frac{k^2\beta}{2} \left[-\beta^2 + \left(-\frac{1}{2}\alpha^2 + \alpha + 2 \right) \beta + \frac{3\alpha^2}{4} + 2k - 2\alpha \right] c + \frac{k^4}{4} \beta \right) \\ & \leq 0. \end{aligned} \quad (\text{A.30})$$

The coefficient of $1 - \gamma$ is a linear function in c and it is positive only if $c \leq$

$$c_{se} = \frac{2\beta k^2(2-\beta)}{(2\alpha^2 - 4\alpha)\beta^3 + (-3\alpha^2 + 8\alpha - 8k + 4)\beta^2 + (-2\alpha^2 + (8k - 8)\alpha + 8k)\beta + 4(k - \alpha)^2}. \quad \text{Also, the constant}$$

part of inequality (A.30) is always positive under the conditions of Proposition 1. Therefore, the inequality (A.30) is satisfied if $c \leq c_{se}$ or $\gamma \leq \gamma_{se} =$

$$\frac{((\frac{\alpha^2}{2} - \alpha)\beta^3 + (-\frac{3\alpha^2}{4} - 2(k - \alpha) + 1)\beta^2 + (2(k - \alpha + \alpha k) - \frac{\alpha^2}{2})\beta + (k - \alpha)^2)\beta c^2 - \frac{k^2\beta c(-\beta^2 + (\frac{\alpha^2}{2} + \alpha + 2)\beta + 2(k - \alpha) + \frac{3\alpha^2}{4}) + \frac{\beta k^4}{4}}{c(1 - \beta)((\frac{\alpha^2}{2} - \alpha)\beta^3 + (-\frac{3\alpha^2}{4} - 2(k - \alpha) + 1)\beta^2 + (2(k - \alpha + \alpha k) - \frac{\alpha^2}{2})\beta + (k - \alpha)^2)c + \frac{k^2\beta(\beta - 2)}{2}}.$$

Under a pure servicizing business model, the firm sells the usage of the product to both high and low segment consumers. Under pooling degree, γ , the optimal usage

of high and low segment consumer is given by $\tau_{H,se}^{*p}$ and $\tau_{L,se}^{*p}$, respectively:

$$\tau_{H,se}^{*p} = \underset{\tau}{U}_{H,se}^p(\tau) = 1 - k(1 - e) - q \quad (\text{A.31})$$

$$\tau_{L,se}^{*p} = \underset{\tau}{U}_{L,se}^p(\tau) = \alpha - k(1 - e) - q \quad (\text{A.32})$$

The firm has to solve the following problem:

$$\begin{aligned} \max_{q,e} \quad & \Pi_{f,se}^p = (q\tau_{H,se}^p - c(1 - \gamma)e^2)M\beta + (1 - \beta)M(q\tau_{L,se}^p - c(1 - \gamma)e^2) \\ \text{s.t.} \quad & U_{H,se}^p(\tau_{H,se}^p) \geq 0 \\ & U_{L,se}^p(\tau_{L,se}^p) \geq 0 \\ & q > 0 \\ & 0 < e < 1. \end{aligned} \quad (\text{A.33})$$

Where the individual rationality constraints require that high and low segments have a non negative utility. The first two constraints in problem (A.33) can be rewritten as follows: 1) $U_{H,se}^p(\tau_{H,se}^p) = \frac{(1-q-(1-e)k)^2}{2} \geq 0$ and 2) $U_{L,se}^p(\tau_{L,se}^p) = \frac{(\alpha-q-(1-e)k)^2}{2} \geq 0$, which are always verified. The KKT conditions provide the following solutions. The solution is given by $\{e_{se}^{*p} = \frac{k(\beta\alpha-\beta-\alpha+k)}{k^2-4c(1-\gamma)}, q_{se}^{*p} = \frac{2(1-\gamma)c(\beta\alpha-\beta-\alpha+k)}{k^2-4c(1-\gamma)}\}$ and yields the firm profit $\pi_{f,se}^{*p} = \frac{(1-\gamma)((\beta-1)\alpha-\beta+k)^2cM}{-k^2+4c(1-\gamma)}$. The profit is positive if $4(1 - \gamma)c > k^2$. The condition for $0 < e_{se}^{*p} < 1$ and $0 < q_{se}^{*p}$ is $\alpha\beta - \alpha - \beta + k < 0$. One can easily show that $\tau_{L,se}^p > 0$ only for $k < 1$. Also, $\tau_{L,se}^p$ and $\tau_{H,se}^p$ are increasing in γ . In order to compare pure servicizing with sharing economy, we focus only on the sets of parameters of Proposition 4. Sharing economy is more profitable than pure servicizing if and only if $\pi_f^{*sh} - \pi_{f,se}^{*p} \geq 0$. It turns out that this inequality is always linear in (γ) and it reduces to:

$$\begin{aligned} & -c(\gamma) \left[\left(\beta^2 + \left((2\alpha + 2)k - \frac{\alpha^2}{2} - 2\alpha \right) \beta + (k - \alpha)^2 \right) c - k^2\beta \right] \\ & + k^2\beta \left[\left(\frac{3 - 2\beta}{8} \right) \alpha^2 - (2 - \beta)\alpha + k \right] c - \frac{k^2}{4} \leq 0. \end{aligned} \quad (\text{A.34})$$

The coefficient of (γ) is a concave quadratic function in parameter c and it is positive if $0 < c < C_{se}^p = \frac{2k^2\beta}{2\beta^2 + (-\alpha^2 + (4k-4)\alpha + 4k)\beta + 2(k-\alpha)^2}$. Also, the constant part is always negative under the conditions of Proposition 4. Therefore, the inequality (A.34) is satisfied if $0 < c < C_{se}^p = \frac{2k^2\beta}{2\beta^2 + (-\alpha^2 + (4k-4)\alpha + 4k)\beta + 2(k-\alpha)^2}$ and $\gamma \leq \gamma_{se}^p = \frac{k^2\beta[(\frac{2\beta-3}{8})\alpha^2 + (2-\beta)\alpha - k]c + \frac{k^2}{4}}{-c[\beta^2 + ((2\alpha+2)k - \frac{\alpha^2}{2} - 2\alpha)\beta + (k-\alpha)^2]c - k^2\beta}$.

In general sharing economy is more profitable than servicing if $c < C_{se} = \min\{C_{se}^h, C_{se}^p\}$ and $\gamma \leq \gamma_{se} = \min\{\gamma_{se}^h, \gamma_{se}^p\}$.

Comparison the environmental performance

The total environmental impact in sharing (EN^{sh}), buy-buy (EN^{bb}), high-buy (EN^{Hb}), pure servicing (EN_{se}^p), and hybrid servicing (EN_{se}^h) by substituting optimal product efficiency and optimal usage are given by:

$$EN^{*sh} = M\beta(e_p + e_u) \quad (\text{A.35})$$

$$EN^{*bb} = M[(1-\alpha)\beta + \frac{2c(\alpha-k)}{2c-k^2}]e_u + e_p \quad (\text{A.36})$$

$$EN^{*Hb} = M\beta(\frac{c(1-k)}{2c-k^2}e_u + e_p) \quad (\text{A.37})$$

$$EN_{p,HL}^{*p,se} = M[\frac{(1-\beta)\alpha - k + \beta}{2} + \frac{k^2}{8c}](e_p + e_u) \quad (\text{A.38})$$

$$EN_{p,H}^{*p,se} = M\beta[\frac{(1-k)}{2} + \frac{k^2}{8c}](e_p + e_u) \quad (\text{A.39})$$

$$EN_{np,HL}^{*p,se} = M[e_p + e_u \frac{2c((1-\alpha)\beta + \alpha - k)}{4c - k^2}] \quad (\text{A.40})$$

$$EN_{np,H}^{*p,se} = M\beta[e_p + \frac{2c(1-k)e_u}{4c - k^2}] \quad (\text{A.41})$$

$$EN_{np}^{*h,se} = M[\beta e_p + \frac{2c(\alpha - k + (1-\alpha)\beta)e_u}{4c - k^2 - 2\beta c}] \quad (\text{A.42})$$

A.8 Proof of Proposition 7.

Under sharing economy model after substituting the optimal efficiency and optimal usage ($\tau_{Hs}^{o*} = 1 - \frac{(1-\beta)\alpha}{2}$, and $\tau_{Ls}^{r*} = \frac{\alpha\beta}{2}$), the environmental impact is $EN^{*sh} =$

$M\beta(\eta_p + \eta_u)$. The aggregate usage is only increasing in β , whereas it is constant in other parameters. The high-segment consumer usage decreases in α but the low-segment consumer usage increases in α . Under buy-buy model, after substituting the optimal efficiency and the optimal usage the environmental impact is $EN^{*bb} = M[(1 - \alpha)\beta + \frac{2c(\alpha - k)}{2c - k^2})\eta_u + \eta_p]$. Sharing economy is always environmentally superior to buy-buy under the production phase. It is environmentally superior under the usage phase if $\beta \leq \beta_e = \frac{2c(\alpha - k)}{\alpha(2c - k^2)}$. However, if $\beta \geq \beta_e$, then sharing-economy is environmentally superior to buy-buy if $\frac{\eta_p}{\eta_u} > \omega^{sh} = \frac{\alpha\beta(2c - k^2) - 2c(\alpha - k)}{(2c - k^2)(1 - \beta)}$.

Under high-buy model, after substituting the optimal efficiency and the optimal usage, the environmental impact is $EN^{*Hb} = M\beta(\frac{2c(1 - k)}{2c - k^2}\eta_u + \eta_p)$. It is clear that the environmental impact under high-buy is always superior to environmental impact under sharing economy.

A.9 Proof of Proposition 8.

The number of the production under sharing economy is β and under hybrid servicingizing is $(\beta + (1 - \gamma)(1 - \beta))$. The difference between the environmental impact of production phase under sharing economy and hybrid servicingizing is equal to $\Delta P = M\eta_p(\beta - ((\beta + (1 - \gamma)(1 - \beta))) = \eta_p(\gamma - 1)(1 - \beta) = M\eta_p P$, which is always negative. Therefore, sharing economy is always environmentally superior to hybrid servicingizing under production phase. In hybrid servicingizing, after substituting the optimal efficiency and the optimal usage, the environmental impact under usage phase is $\eta_u \frac{2c(1 - \gamma + \gamma\beta)((\alpha - k) + \beta(1 - \alpha))}{2(-\beta + 2)(\beta\gamma - \gamma + 1)c - k^2}$, which is increasing in both α and γ . The difference between the environmental impact of usage phase under sharing economy and hybrid servicingizing is equal to $\Delta U = M\eta_u \frac{2(\beta^2 - (\alpha + 1)\beta - k + \alpha)(-\beta\gamma + \gamma - 1)c - k^2\beta}{2(-\beta + 2)(\beta\gamma - \gamma + 1)c - k^2} = M\eta_u U$. Now, sharing economy is better than hybrid servicingizing environmentally if $\Delta = M\eta_p P + M\eta_u U < 0$, which depends on η_u and η_p . Since P is always negative, then $\Delta < 0$ if and only if $\frac{\eta_p}{\eta_u} > \frac{-U}{P} = \frac{-2(-\beta^2 + (\alpha + 1)\beta + k - \alpha)(\beta\gamma - \gamma + 1)c + \beta k^2}{2(1 - \gamma)(1 - \beta)((\beta - 2)(\beta\gamma - \gamma + 1)c + \frac{k^2}{2})} = \omega_{se}^h$. It is clear that if $U < 0$, this condition is always satisfied. From inequality (A.26), it is clear that the

denominator of expression ω_{se}^h is always negative. If the nominator of expression ω_{se}^h is positive; then the condition $\frac{\eta_p}{\eta_u} > \omega_{se}^h$ is always hold since $\omega_{se}^h < 0$. This happens if $(-\beta^2 + (\alpha + 1)\beta + k - \alpha) < 0$, which can be written as $\alpha > \alpha_1 = \frac{\beta+k-\beta^2}{1-\beta}$. However if $\alpha < \alpha_1$, then $\omega_{se}^h < 0$ if $\gamma > \gamma_e = \frac{2c\beta^2 + ((-2\alpha-2)c+k^2)\beta - 2c(-\alpha+k)}{2(-\beta^2 + (\alpha+1)\beta + k - \alpha)(\beta-1)c}$.

A.10 Proof of Proposition 9.

Under Pure servicing model, after substituting the optimal efficiency and the optimal usage, the environmental impact under the production phase is $M(1 - \gamma)\eta_p$, and under the usage phase is $\frac{2(1-\gamma)cMe_u(\beta-k+(1-\beta)\alpha)}{4c(1-\gamma)-k^2}$. Sharing economy is environmentally superior to pure servicing under production phase if $P = (\beta - (1 - \gamma)) < 0$, which can be written as $(1 - \gamma) > \beta$. Under the usage phase sharing economy is better than pure servicing if $U = \frac{2c(k-\alpha+(1+\alpha)\beta)(1-\gamma)-k^2\beta}{4c(1-\gamma)-k^2} < 0$. Now, sharing economy is better than pure servicing environmentally if $\Delta = M\eta_p P + M\eta_u U < 0$, which depends on η_u and η_p . If the expression $P > 0$, then Δ is negative only if $\eta_p < \frac{-U}{P}\eta_u$, which can be written as $\frac{\eta_p}{\eta_u} < \frac{2c(k-\alpha+(1+\alpha)\beta)(1-\gamma)-k^2\beta}{(4c(1-\gamma)-k^2)((1-\gamma)-\beta)} = \frac{-U}{P} = \omega_{se}^p$. It is obvious that $U < 0$ in order to satisfy the condition. However, if $P < 0$, then $\Delta < 0$ if $\eta_p > \frac{-U}{P}\eta_u$, which can be written as $\frac{\eta_p}{\eta_u} > \frac{-U}{P} = \omega_{se}^p$. It is clear that if $U < 0$, this condition is always satisfied. One can easily show that $U < 0$ if $\alpha > \alpha_2 = \frac{k+\beta}{1-\beta}$. As a summary the conditions where sharing economy is superior to pure servicing environmentally can be summarized as follows:

- $\gamma > 1 - \beta$ and $\frac{\eta_p}{\eta_u} < \omega_{se}^p$
- $\gamma < 1 - \beta$ and $\frac{\eta_p}{\eta_u} > \omega_{se}^p$

Vita

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