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Should I endorse a third party? Authorization strategies for brand manufacturers in a refurbishing market

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Abstract

Original equipment manufacturers (OEM) may have little or no control over third-party (3P) refurbishing firms. With the rapid growth of the refurbished market for electronic products, we study whether it is beneficial for an OEM to cooperate with a 3P via authorization schemes that boost an OEM's brand reputations, increase their sales, and strengthen consumer acceptance of authorized 3P's refurbished products. We examine the conditions under which both the OEM and the 3P benefit from the authorization strategy, studying the trade-off between the indirect benefit of authorizing a 3P to increase market share and the downside of cannibalizing new-product sales. To estimate our model's behavioral parameters, we conduct an extensive experiment on MTurk to capture consumer preferences and cannibalization effects. The experimental study examines the price-perceived quality relationship along with brand value, seller identity (OEM, 3P), and product condition; its results show that the discount and seller identity play a large role in consumer choice and that cannibalization is generally linear in price. We subsequently construct a revenue maximizing model that incorporates this linear cannibalization effect, along with the authorization fees. We show that refurbished products offered by authorized 3Ps have higher demand than those that are not authorized and that it is beneficial for 3Ps to participate in these schemes despite the authorization fees. We conclude that authorization can be a win-win strategy for OEMs and 3Ps, especially when low-end consumer demand and average reduction of refurbishing costs are relatively high, and the level of cannibalization is relatively low. To achieve win–win solutions, it is important for OEMs and 3Ps to consider brand recognition, consumer behavior related to refurbished products, and remanufacturable supply.

Keywords: Refurbishing, authorization, cannibalization, customer behavior

1 Introduction

Refurbishing as a production strategy has been shown to have many benefits. It not only helps companies increase their profitability but also leads to business development, gains in energy conservation, and has environmental and social benefits (Xu et al, 2019). It reduces resource consumption, curbs carbon emissions, limits landfill, decreases cross-continent transportation, creates skilled jobs, and promotes social sustainability (Charter and Gray, 2008; Yan et al, 2015; Wu and Zhou, 2019). Therefore, OEMs increasingly capitalize on refurbishing. Some global brands, such as Xerox, Caterpillar, Boeing, Apple, Samsung, and Dell, consider refurbishing to be among their most important business strategies (Krikke et al, 2004; Ovchinnikov et al, 2014; Wu and Zhou, 2019; Xu et al, 2019). For example, refurbishing has helped Xerox realize over US$127 million in cost benefits and saved over 11.5 million pounds of greenhouse gasses (Drzewiecki, 2017). Apple, Samsung, Lenovo, Dell, Canon, Hewlett-Packard, Panasonic, and Epson are undertaking similar activities for their various electronic products. After integrating refurbishing into their business models, they sell the refurbished products on their official websites, as well as on online marketplaces such as Amazon and eBay.

Although refurbishing has great economic potential, not all OEMs choose to refurbish their products. According to Ferguson and Toktay (2006), cost and internal cannibalization are the two main reasons some OEMs do not refurbish. Some OEMs that are capable of refurbishing used products worry about the cannibalization threat to the sales of their new products (Guide and Li, 2010; Agrawal et al, 2016), because refurbished product versions are sold at lower prices than new products. In an empirical study, Agrawal et al (2015) indeed show that the presence of OEM-refurbished products has a negative impact on the perceived value of new products. Consequently, refurbishing sectors have been dominated by third-party (3P) refurbishing firms that offer refurbished versions of new products from OEMs (Ferguson, 2010). Hauser and Lund (2008) determine that 94% of approximately 2,000 refurbishing firms are third parties, usually small to medium in size, with revenues ranging from US$500,000 to US$5,000,000. OEMs cannot control the existence of 3Ps, especially those that sell electrical and electronic products (Liu et al, 2018). Third-party–refurbished products cannibalize OEMs' new products, resulting in competition between refurbished and new products (Atasu et al, 2008; Agrawal et al, 2015; Liu et al, 2018). An OEM may argue that the presence of third-party firms may negatively affect their own business model due to the impact on new product sales. Alternatively, from an OEM's perspective, the presence of 3Ps may increase the perceived value of new products (Agrawal et al, 2015), and hence be beneficial to their business model.

Rather than fully focusing on their own refurbishing operations, or letting 3Ps run the refurbishment market fully independently, OEMs may also decide to actively cooperate with 3Ps (Yan et al, 2015; Xiong et al, 2016; Liu et al, 2018; Ma et al, 2018). To this purpose, more and more OEMs have been adopting refurbishing-authorization schemes as forms of cooperation. In such schemes, 3Ps obtain proprietary rights from OEMs to refurbish used products for a fee, and re-market them using OEM-authorized signage, without the operational participation of the OEMs (Zou et al, 2016). Apple recently established an agreement with Amazon to allow listings of Apple's product line on Amazon's online store (Business, 2018; NotebookCheck, 2018), such that any Apple products obtained directly from Apple or its authorized third parties (A3Ps) can be sold and shipped by Amazon. In return, Amazon agrees to remove from its site all unauthorized third parties (U3Ps) that sell new or refurbished Apple products. To sell refurbished Apple products in the Amazon online store, firms must apply to become authorized Apple third parties, agree to meet certain requirements (e.g., assurance of product quality), and pay fees to Apple. As an authorized Apple refurbisher, 3Ps may increase their reputation, charge a premium price, and obtain access to sales channels like Amazon that otherwise would not be accessible. Authorization allow OEMs to inspect and review their A3Ps to ensure they meet OEM standards. For example, through its product recycling program, Lenovo strongly encourages A3Ps to achieve recycling standards, including https://www.nsf.org/knowledge-library/responsible-recycling-r2 and http://e-stewards.org/, and to meet other environmental, safety, health, business control, and security standards (Lenovo, 2019). The authorization strategy also allows OEMs to increase their revenues from authorization fees and royalties. For 3Ps, cooperating with OEMs through authorization scenarios can increase their sales volumes and improve consumer acceptance of refurbished products. While an increasing number of 3Ps engage in such operations, many other third parties refurbish used products and market them without authorization from manufacturers, labeling them as "seller refurbished" and listing them on eBay; according to eBay, a "seller refurbished" item is one that "has been restored to working order by the seller or a third party that is not authorized by an OEM" (eBay, 2019).

However, an authorization strategy also may be risky for OEMs. Because it leads to an increase in customers' perceptions of the quality of authorized refurbished products, it may cause cannibalization of new product versions. For customers, buying authorized refurbished products is a way to find reliable products at bargain prices. The risks could be greatest for OEMs that have premium name brand, because customers may prefer to have good-quality refurbished products from name brands that are available at lower prices and have similar warranty periods as new versions. Although authorization scenarios seem to benefit 3Ps, the parties may not accept the authorization contracts offered by OEMs. In most cases, the 3Ps are concerned about the costs of new developments related to contracts, certification, inspection, and royalty fees (Oraiopoulos et al, 2012; Zou et al, 2016; Liu et al, 2018).

The goal of this paper is to study the decisions that OEMs and 3Ps should make with regard to authorization. To that end, we first determine empirically how the discount on refurbished products impacts the cannibalization of new products. We conduct a discrete choice experiment (DCE) to estimate the demand and study consumer behavior w.r.t. the choice between new and refurbished products. Expanding on prior knowledge, our research employs DCE to uncover consumer inclinations, particularly focusing on responsiveness to discounts, within a context involving OEMs of varying brand values (both high and low), different seller identities (authorized and unauthorized third-party), and encompassing both new and refurbished products. Our empirical investigation not only enriches our model but also independently imparts valuable insights to researchers and managers regarding consumer decision-making within these scenarios. Cannibalization is also affected by the OEM's brand recognition, the product condition and seller identity. In particular, we are interested in how the brand value of the OEM and the 3P seller identity (authorized vs unauthorized) impacts cannibalization. After having established this behavior, we determine the optimal refurbishing strategy for the OEM and the 3P's - both authorized and unauthorized. We determine the conditions needed for the OEM and a 3P to engage in an authorization scheme, the range of acceptable authorization fees and the optimal fee the OEM should charge.

Prior research has shown that it is ideal for OEM's to cooperate with 3P's, especially as the refurbished product market is growing rapidly (Yan et al, 2015; Xiong et al, 2016; Liu et al, 2018; Ma et al, 2018). Much literature on refurbishing addresses the competition between OEMs and 3Ps. Majumder and Groenevelt (2001) were the first to propose a model to investigate the interactions between OEMs and 3Ps. According to prior literature, OEMs compete with 3Ps, the existence of refurbished products influences OEM decisions, and consumer behavior affects OEM and 3P decisions. But literature has yet address how these effects manifest, especially with regard how refurbished products influence price, quantity, and refurbishing authorization decisions. Because consumer behavior toward new and refurbished products differs due to varying perceptions of product quality, it is important to consider consumer behavior when solving the pricing problem, which directly affects demand for refurbished products.

Some recent articles study technology licensing or authorization related to refurbishing. Oraiopoulos et al (2012) propose a model in which OEMs charge relicensing fees to consumers who purchase their refurbished products. Zou et al (2016) compare outsourcing with authorization, and Hong et al (2017) compare royalty licensing and fixed-fee licensing in the refurbishing mode. Both papers assume that relicensing/authorization is mandatory for 3Ps and that 3Ps cannot engage in refurbishing products without a license to refurbish. Huang and Wang (2017) consider information sharing in technology-licensed refurbishing scenarios. Liu et al (2018) study the conditions in which it is optimal for OEMs to use the authorization strategy; however, they do not consider real-market consumer behavior and used-product availability. Zhou et al (2021) shed light on the intricate competition involving original equipment manufacturers (OEMs), authorized remanufacturers (ARs), and unauthorized remanufacturers (URs) within the realm of remanufacturing strategies. Their study explores scenarios where new, authorized remanufactured, and unauthorized remanufactured products coexist, and examines the strategic decisions OEMs face. By employing a game-theoretic model, the authors reveal insights into optimal production quantities, product quality, and the dynamics of authorization fee contracts. Jin et al (2022) analyze the OEM-3P authorization problem while comparing dealer authorization (DA, where OEM sells the refurbished product collected by the 3P) and a remanufacturing authorization (RA, where the 3P sells the products). In their study on closed-loop supply chains, Zheng and Jin (2022) explore two relicensing scenarios: one where the OEM licenses retailers for remanufacturing (Model R), and another where third parties are authorized (Model TP). Employing game-theoretical models, they compare quantities, profits, consumer benefits, and environmental impacts between these models. The study's findings reveal that the Model TP yields higher OEM profits compared to Model R, while Model R showcases better environmental performance. When consumer willingness-to-pay for remanufactured items is substantial, Model R proves advantageous from supply chain and societal perspectives. Moreover, in their study, Lv et al (2023) discuss the common strategy of authorization adopted by original equipment manufacturers (OEMs) to compete with remanufacturers. They explore how this remanufacturing authorization strategy may encounter new options in a new market segment. Their research investigates two authorization strategies that OEMs can use to cooperate with remanufacturers: unit fee and fixed fee.

Most research above assumes that willingness to pay (WTP) drives consumer behavior, such that demand for refurbished products decreases as prices of products increase. They make the traditional WTP assumption for demand, and show that the OEM always prefers RA over DA. Within the operations management literature on refurbishing, demand cannibalization has been implicitly incorporated by many authors using the extended Hotelling line model, in which consumers have valuation $v \in U[0,1]$ for the new product and δv for the refurbished product. Agrawal et al (2015) estimate δ using a behavioral experiment; they also estimate a change in the valuation of the new product once the refurbished product is introduced. Abbey et al (2015) discuss consumer perceptions for refurbished products; while Abbey et al (2019) discuss refurbishing and consumers' risky choices. Guide and Li (2010) estimate cannibalization using eBay auctions while Ovchinnikov (2011) and Kurdhi et al (2023) use explicit cannibalization function and estimate it via a behavioral study. Our paper extends prior cannibalization analysis. We consider multi-segment cannibalization demand model where the firm's decisions are guided by estimating the fraction of consumers who, for a given price difference, would switch from the new to the refurbished products. We investigate the effect of market segmentation on optimal strategy. Further, unlike our model, the previous models does not include collection and refurbishing costs, and availability of used products is unconstrained. For 3P's, not only do refurbishing and collection costs severely cut into profit margins, but the availability of used products has a substantial impact on their business strategy. We argue that both these factors play a role in staying profitable and whether to accept an authorization program. Table 1 shows the positioning of our model in the literature.

Table 1: The positioning of this paper in the literature

Papers	Consumer Behavior	Demand Cannibalization	Market Segmentation	Supply Constraint
Zou et al (2016)	WTP	No	Heterogenerous	No
Hong et al (2017)	WTP	No	Heterogenerous	No
Huang and Wang (2017)	WTP	No	Heterogenerous	No
Liu et al (2018)	WTP	No	Heterogenerous	No
Zhou et al (2021)	WTP	No	Heterogenerous	No
Jin et al (2022)	WTP	No	Heterogenerous	No
Zheng and Jin (2022)	WTP	No	Heterogenerous	No
Lv et al (2023)	WTP	No	Heterogenerous	No
This paper	Preference	Explicit function	High & Low-end segments	Yes

OEMs also need to account for the availability of used products in a given region when considering authorization programs. Market presence plays an important role in the 3P's collection efforts, and may limit its access to used products. Saphores et al (2009) conducted a national survey of U.S. households and found that on average, each household had 4.1 small and 2.4 large electronic waste (e-waste) items in storage, more than estimates by the United States Environmental Protection Agency (US EPA), suggesting that the backlog of e-waste in the United States is larger than generally believed. Sabbaghi et al (2015) observe that compared with household consumers, commercial consumers have more stored computers, regardless of brand and capacity factors. Sabbaghi et al (2016) point out that consumers tend to store their unwanted electronic devices after the last time of usage. According to the US EPA, e-waste has increased by 120% in the past decade, and only 25% of it is collected for recycling or reuse (PMR, 2017). Therefore, the volume of used products that could be collected is huge. We study the authorization strategy under both these conditions - unconstrained and constrained access to used products.

In this paper, we incorporate real-market consumer behavior, market segmentation, and used-product availability in determining the optimal pricing decisions for a 3P, as well as whether they should participate in the OEM's authorization scheme. We also show the right authorization strategy that the OEM should follow in order to achieve a win-win situation. Our study contributes to the existing literature in several ways. Our empirical work outlines the nuanced relationship between price, brand, seller identity and product condition for refurbished smartphones. We show that in a competitive environment, cannibalization is largely linear in the discount offered, unlike the quadratic form that was earlier observed in a monopolistic setting (Ovchinnikov, 2011). In our experiment, a quadratic form is observed only for the refurbished product of the low-brand valued firm when the discount offered is very large. However, such large discounts are not optimal to set, because the 3P needs to recover their refurbishing costs. We find that the higher the seller reputation, refurbished products are a much closer substitute for new products. We show that authorized 3Ps are able to attract higher demand compared to their unauthorized peers. Further, we incorporate the empirical findings in a model to determine the optimal refurbishing strategy for both the OEM and the 3Ps. By adding used-product availability as a constraint, we are able to show how it plays an important role in pricing and the authorization decision. The OEM could gain from high fees, but it leads the 3P to charge a higher price for the refurbished product which decreases the products it sells in the market. We show the range of acceptable fees that can lead to authorization agreements. To the best our knowledge, our research is the first to combine consumer behavior, cannibalization and used product availability with authorization strategy.

The rest of the paper is organized as follows. Section 2 outlines our experimental study, and Section 3 describes our model setup. We discuss the optimal strategies in Section 4 and discuss the implications of our findings in Section 5.

2 Estimating Discount Elasticities: Experimental Study

In this section, we investigate the relationship between perceived quality of the refurbished product and its offered discount when there is a new product in the same market. According to Völckner and Hofmann (2007), a price that is too low may produce a negative signal that lowers consumer perceptions, so managers should be aware of these effects before trying to promote new products by offering discounts. In practice, many firms adopt a discount strategy by setting their refurbished product prices. In line with Völckner and Hofmann (2007), Ovchinnikov (2011), and Abbey et al (2015), we fix the price of the new product, which allows us to view the degree of cannibalization as a function of the discount offered. This effect could be nonlinear, implying increased negative perception if the discount is too high. Hence, we consider the purchasing behavior of refurbished products as a function of discount levels relative to the new product price, in order to examine the non-linearity and the negative effects at lower prices due to the potential effects of the price-perceived quality relationship. In this study, we manipulate the seller identity (OEM, authorized 3P, unauthorized 3P), price discount, brand combination and product condition to measure quality perceptions.

2.1 Experimental Design

We use a discrete choice experiment to estimate the demand and study the consumer behavior w.r.t. the choice between the new and refurbished products of the two brands. In this common consumer behavior elicitation technique in marketing literature, respondents see a set of alternatives and choose their favorite. According to Louviere et al (2010), the DCE is based on random utility theory, which assumes that respondents seek to maximize their utility. It is more consistent with economic demand theory and provides a realistic view of people's decision making. The DCE has been adopted by many practitioners to develop empirical studies in marketing and other applied economic fields for which choices play important roles, due to its high interpretability, which enables practitioners to verify their compliance with well-established behavioral theories (McFadden, 1974).

Factors such as price discount (Ovchinnikov, 2011; Abbey et al, 2015), seller identity (Subramanian and Subramanyam, 2012; Agrawal et al, 2015), product condition (Ovchinnikov, 2011; Neto et al, 2016) are shown to influence the consumers' willingness to pay and purchase decisions for refurbished products. In the experiment, we manipulate the seller identity (OEM, authorized third party, unauthorized third party), the product condition (used, refurbished, Open Box), and the discount offered on the full price of the new phone (at levels 10%, 20%,..., 90%, 95%). Each respondent answers questions where parameters of these categories are randomly chosen. Details of the experiment can be found in Appendix B, see also Kurdhi et al (2023) for additional details. The discount range is in line with Ovchinnikov (2011) and Abbey et al (2015). Table 2 illustrates examples of tasks for each study in which the respondents had to make a choice. We selected the subset of choice tasks presented to the respondents based on efficient design using Ngene software version 1.2 (Choicemetrics, 2018). Each respondent faced 20 choice tasks. Each of these tasks was a choice between two refurbished alternatives and a new alternative with no discount. This experiment was conducted on Amazon's MTurk (details outlined later in this subsection).

But first, we wanted to clearly identify brand perceptions. It is important to chose actual brands, to elicit realism in the preferences revealed by participants in the experiment. This is a common approach in marketing literature, where experiments include brands with high consumer awareness. We concentrated on a specific product (smartphone) and the experiment was conducted for Apple and Motorola - firms with clear differences in perceived brand strength. We employ Apple as a high-end brand, to be consistent with previous studies (e.g., Abbey et al, 2017; Agrawal et al, 2015; Abbey et al, 2019; Kurdhi et al, 2023), and include Motorola as a low-end brand. This is also consistent with general public opinion, Global-Brands-Magazine (2023) place Apple at #2 in the world, and Motorola at #9. To confirm these assumptions, we conducted a quick survey on Amazon's MTurk, where we received 65 responses from participants who were asked to rank Apple, Samsung, and Motorola on a scale of 1 to 3 based on perceived quality and overall trustworthiness. Following Abbey et al (2015), we consider three major elements of brand equity. The first element is brand awareness, which is implicit in the choice between low and high brand equity options. The second element is the perceived quality of these high and low equity brands. Finally, we include trust in the brand. Trust and quality perceptions are among the most important elements of brand equity and are of particular interest when a past failure has occurred. The results reveal a distinct preference for Apple, with 60% of respondents considering it to be the highest in both quality and trustworthiness. Samsung secured 27.69% of the preferences, while Motorola received 12.31%. These findings underscore Apple's dominant position in terms of brand perception, suggesting potential implications for the market positioning strategies of smartphone manufacturers. It is important to note that the survey's scope was limited to the selected brands and may not comprehensively capture broader consumer sentiment within the smartphone industry.

Table 2: Example of choice task

Attributes	Option A	Option B	Option C
Brand	Apple	Apple	Apple
Product Condition			
Seller Identity	Unauthorized Third Party	Authorized Third Party	Original Manufacturer (Apple Inc.)
Price (Discount)	$360 (40% discount)	$60 (90% discount)	$600
Your Choice	☐	☐	☐

Using Biogeme (Bierlaire, 2016, 2020), we fit the choice data to a multinomial logit model (MNL) and latent class (LC) model. Biogeme is open-source software designed to estimate various discrete choice models using maximum likelihood estimation. The MNL model is most widely used for discrete choice modeling. The underlying assumption in this model is that consumers are homogeneous in their preferences. Furthermore, the LC model states that the different classes exist in the consumer population, each with homogeneous preferences. However, these preferences differ among classes. To capture these preferences, we estimate each class with separate MNL models.

The experiment was conducted using an online panel offered by Amazon Mechanical Turk (MTurk), a crowd-sourcing marketplace for simple assignments, including data collection, surveys, and text analyses. The low cost and high speed of data collection are two significant strengths of the MTurk. Since we are primarily interested in obtaining consumer insights, MTurk allows us to obtain access to a much wider set of respondents than in an on-campus lab with student participants. MTurk has been successfully used in multiple empirical studies on refurbishing (Agrawal et al, 2015; Hazen et al, 2017; Abbey et al, 2017; Esenduran et al, 2020) and in other fields (Ülkü et al, 2012; Hutchison-Krupat and Chao, 2014; Tokar et al, 2016; Lee et al, 2018a). Paolacci et al (2010) point out that MTurk offers a viable data collection alternative, in that results obtained from MTurk do not significantly differ from those found in laboratory settings. Several studies confirm the lack of significant differences between traditional samples and online respondents (e.g., Horton et al, 2011; Suri and Watts, 2011; Goodman et al, 2013). For an extended discussion on the use of MTurk in behavioral studies, see Buhrmester et al (2011), Peer et al (2014), Landers and Behrend (2015), Follmer et al (2017), and Lee et al (2018b). We obtained 1,014 valid responses after an attention check procedure on the response pattern and time. We added a manipulation check to ensure that the respondents clearly understood the differences among product conditions and seller identities. Appendix B includes the full experimental instrument.

2.2 Experimental Results

Table 3 and Figure 1 present the key statistics of interest for the MNL model[1]. Our main observation is that for both high- and low-brand, the discount and seller identity have the highest importance. Also, in all brands, the average part-worth utilities are increasing in the discount offered.

We calculate the utility of both new and refurbished products given its discount and condition and then obtain the purchase probability for a given product as a ratio of the exponent of its utility to the sum of exponents of utilities of all alternatives in the choice set. Figure 2 illustrates the change in

[1]The complete output of the discrete choice experiment is presented in Appendix C.

Table 3: Relative importance of attributes for MNL model

	Apple		Motorola	
Attributes	Utility Range	Relative Importance	Utility Range	Relative Importance
Discount	1.746	60.60%	1.689	58.35%
Product condition	0.247	08.56%	0.375	12.95%
Seller identity	0.888	30.84%	0.831	28.70%
Sum	2.881	100%	2.895	100%

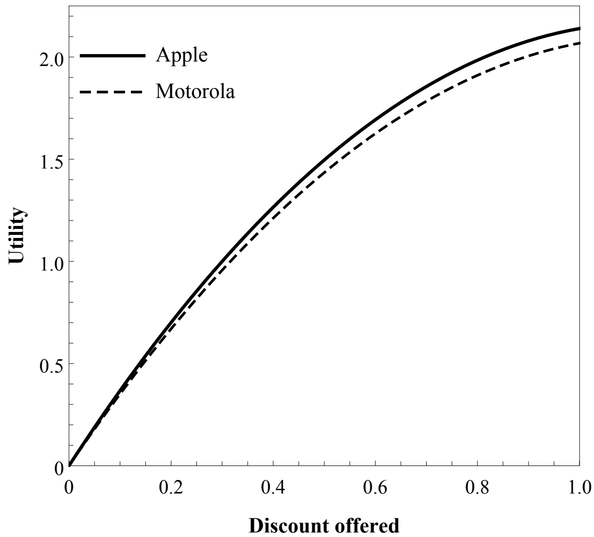
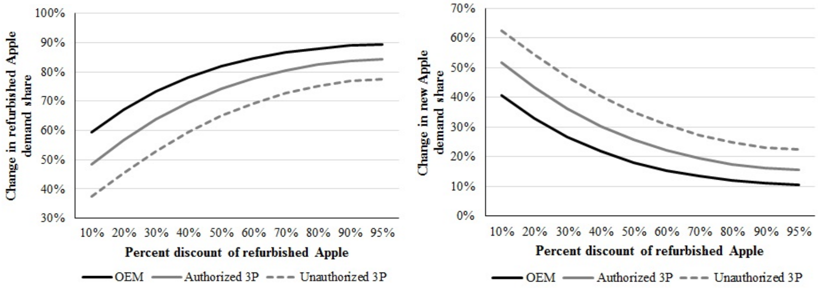


Fig. 1: Utility functions of discount offered in the MNL model

demand share of Apple refurbished and new products from discount increases of the refurbished product (demand share for Motorola smartphone can be seen in Appendix C). The results obtained for Apple and Motorola are similar. Concerning the three categories of refurbished products with respect to the seller identity, we find that the higher the seller reputation, the refurbished products are a much closer substitute for new condition products.

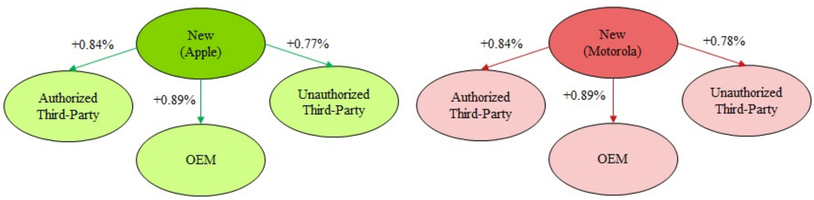
In Figure 3, we show the cross-discount elasticities for Apple and Motorola smartphones The values in the figures represent the effect of a 1% increase in the discount offered on the refurbished product on the cannibalization levels. For example, Figure 3a shows that a 1% increase in the discount of OEM refurbished Apple increase its market share by 0.89%, a 1% increase in the discount of Authorized third party refurbished products increase its market



(a) Refurbished Apple (b) New Apple

Fig. 2: Change in demand share of refurbished and new products from discount increases of refurbished products in the MNL model

share by 0.84%, whereas a 1% increase in the discount of Unauthorized 3P refurbished products increase its market share by 0.77%. Thus, the OEM or Authorized refurbished products pose a big threat of cannibalization to new products. Although refurbished products sold by OEM and authorized third party have the same quality and are certified by the OEM, the reputation of the sellers seems to influence the quality perception of their products. The authorization strategy will increase the cannibalization level of third party refurbished products. The results obtained for Apple and Motorola are similar.



(a) Apple (b) Motorola

Fig. 3: Discount elasticity between new and refurbished products for (a) Apple and (b) Motorola products in the MNL model

We also analyze the survey results assuming a latent class model (LC). Detailed results of the LC model are presented in the Appendix C. Latent Class

Models assume that different groups or classes with internally homogeneous preferences exist in the population, but that the preferences between the classes differ (Greene and Hensher, 2003). Separate MNL models are estimated for each class and for each individual the chance of belonging to the group (or class) is estimated. We intend to find whether any classes exhibit a non-linear utility in discount (like the inverted U-shape in Ovchinnikov (2011)). Hence, the model with two classes is chosen to achieve the goal, i.e., a class with a linear discount (LD) and a class with a quadratic discount (QD). The two-class model has good interpretability and by setting this to all brands, we can observe the differences between the two brands.

We find that the QD class is significant for Motorola, i.e. the low-brand valued firm. However, the percentage of customers that show is behavior is very low (15%) and around 85% of consumers are associated with the LD class. Furthermore, the quadratic nature becomes apparent only at very high discount levels ($> 50\%$). Such high discounts are not observed in reality, because the seller needs to recover at least the refurbishing cost of the product.

3 Model

We consider a supply chain that consists of a manufacturer (OEM) that produces a new product and a third-party (3P) that collects, refurbishes and sells used products. It costs the OEM c_n per unit to produce the new product, which it sells at the fixed price of p_n. This price is fixed until the next generation is introduced (Ovchinnikov, 2011; Hartl et al, 2019). In this case, the consumers do not have an incentive to wait with purchasing the new product until the price has dropped sufficiently. The 3P incurs a unit production cost of c_r, which is lower than the unit production cost of the new product

$c_r < c_n$. The 3P is free to set the price p_r for the refurbished product such that it maximizes its profits.

Table 4: Notation and associated description

Symbol	Description
$M_o(M_t)$	OEM (third party)
p_n	Price of new product
p_r^j	Price of refurbished product for case j, where $j \in \{U, A\}$
c_n	Unit manufacturing cost of a new product
w_n	Unit margin of new product, where $w_n = p_n - c_n$
c_r^j	Unit refurbishing cost a refurbished product for case j, where $c_r^U > c_r^A$
g	Authorization fee
c_g^A	Marginal refurbishing cost of third party after being authorized, where $c_g^A = c_r^A + g$
Q_n	Demand for new products when there is no refurbished unit available
$q_n^j(q_r^j)$	Number of consumers purchasing new (refurbished) product for case j, where $j \in \{U, A\}$
α^j	Fraction of high-end customers who switch to purchase refurbished product for case j
δ	Fraction of the cores available to the third party
k^j	price elasticity on market demand of low-end customers for case j, where $k^A > k^U$
b^j	Cannibalization coefficient for case j, where $b^A > b^U$
$\Pi_o^j(\Pi_t^j)$	Profit function of the OEM (third party) for case j, where $j \in \{U, A\}$
Symbols used for simplification of expressions:	
r^j	Cannibalization elasticity for case j, where $j \in \{U, A\}$, $r^U = b^U Q_n$ and $r^A = b^A Q_n$
d^j	Composite effect of the refurbished product's price for case j, where $j \in \{U, A\}$, $d^U = k^U + r^U$ and $d^A = k^A + r^A$

The market is divided into two segments: high end and low end. Customers at the high end are willing to purchase new products, whereas customers at the low end purchase only refurbished products at lower prices. In the absence of refurbished products, the demand for new products (i.e., high-end demand) is Q_n. In the presence of the refurbished product market, a fraction $\alpha(p_r) \in [0, 1]$ of customers at the high end switch to refurbished products - if they are available. By offering a refurbished product at price p_r, a 3P attracts $k(p_n - p_r)$ low-end customers who will not purchase new products. The number of consumers who purchase new and refurbished products for the unauthorized case are as follows:

$$q_n = Q_n(1 - \alpha(p_r)), \tag{1}$$

$$q_r = k(p_n - p_r) + \alpha(p_r)Q_n. \tag{2}$$

The OEM has an authorization strategy it can offer to the 3P, where it sets the authorization fee g for each refurbished product that the 3P sells. In the presence of such a strategy, the 3P has to decide whether to accept the authorization program offered by the OEM, or to remain unauthorized. Let the superscripts "U" and "A" denote the unauthorized and authorized cases respectively. Engaging in the authorization program has several benefits for the 3P. It reduces its refurbishing cost to $c_r^A < c_r^U$, due to the technical support provided by the OEM. The refurbished product also benefits from higher perceived quality which increases the demand for it both in the high-end cannibalized segment (since $\alpha^A > \alpha^U$), and the low-end consumer segment (since $k^A > k^U$). These differences represent the benefits brought out by access to marketplaces such as Amazon and the increased visibility from authorization. We summarize our notation in Table 4, where superscripts "U" and "A" denote the unauthorized and authorized refurbishing cases, respectively. In the unauthorized case, the profit of OEM is:

$$\Pi_o^U = (p_n - c_n)q_n^U, \tag{3}$$

Let δ be the fraction of the cores that the 3P has access to for collection. We assume that collection cost is linear in the quantity collected and is included in c_r^U (in line with Ferrer and Swaminathan (2006) and Atasu et al (2008)). Thus, the optimization problem for the U3P is:

$$\begin{aligned} &\max_{p_r^U} \Pi_t^U(p_r^U) = (p_r^U - c_r^U)q_r^U \qquad (4) \\ &\text{s.t.} \quad 0 \le q_r^U \le \delta q_n^U, \end{aligned}$$

In the refurbishing authorization program, the manufacturer sets the authorization fee, and this can be set as high as necessary. The 3P collects and refurbishes used products of the manufacturer, and decides whether to accept the authorization program. The 3P pays the OEM an authorization fee g for each unit refurbished product, according to a royalty licensing contract. Since the fraction of high-end customers switching after the 3P being authorized is higher than that before the firm take the authorization program, the OEM always sets $g \geq 0$. In this case, the total marginal refurbishing cost of the 3P is $c_g^A = c_r^A + g$, where $c_r^A < c_r^U$ is the refurbishing cost. Then, the optimization problem for the OEM is as follows:

$$\max_{g} \Pi_o^A = (p_n - c_n)q_n^A + gq_r^A, \tag{5}$$

and the optimization problem for the A3P is:

$$\max_{p_r^A} \Pi_t^A(p_r^A) = (p_r^A - c_g^A)q_r^A \tag{6}$$
$$\text{s.t.} \quad 0 \leq q_r^A \leq \delta q_n^A.$$

In our model, the 3P needs to choose whether to accept the authorization program offered by the OEM, and the OEM needs to determine the authorization fee and whether to authorize the 3P. The OEM can set an authorization fee, while the 3P has to decide on price of refurbished product, and whether to accept the authorization. We analyze the acceptable authorization fee for both the OEM and the 3P. The 3P is willing to accept authorization whenever its profit increases after being authorized. Likewise, the OEM is willing to authorize the 3P if the authorization strategy benefits the OEM's profit.

4 Refurbishing Authorization Strategy

In our main discussion, we analyse the refurbishing authorization strategy with linear switching function. This assumption is more in line with our behavioral results, that is the average part-worth utilities are increasing in the discount offered for the MNL model (see, Figure 1). Although we find a class with a quadratic discount in the LC model for Motorola smartphone, the percentage of respondents in the class is relatively small compared to that in a class with linear discount (see, Table C1). This behaviour is only observed when discounts are quite high. Such high discounts are not observed in reality, especially since the 3P needs to recover at-least the refurbishing costs. We assume that cannibalization mimics a general linear switching function, that is

$$\alpha^U(p_r^U) = b^U(p_n - p_r^U) \tag{7}$$

for some coefficient b^U. The switching function for authorized scenario is formulated by

$$\alpha^A(p_r^A) = b^A(p_n - p_r^A) \tag{8}$$

for some coefficient b^A. Figure 4 shows the increase in the cannibalization fraction that results from the authorization of the 3P, represented by $\tau_b > 0$, where $b^A = b^U + \tau_b$. The fraction of switching customers always increases if the 3P is an authorized refurbisher.

We assume the 3P has access to $100 * \delta\%$ of the cores for collection. In the steady-state model, we assume products have a useful life of one period, with all units available thereafter for collection. Every item collected is assumed to be suitable for refurbishing. To find our optimal solutions, we solve for the

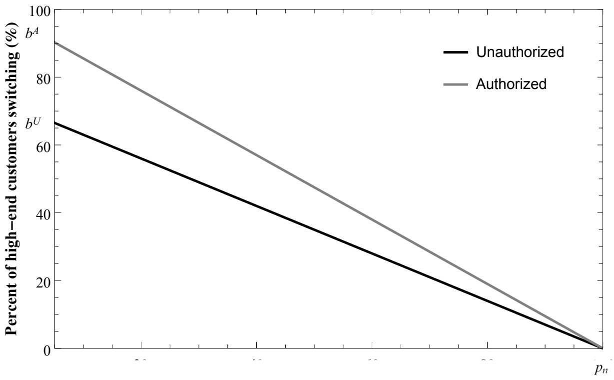


Fig. 4: The relationship between refurbished product's price and percent of high-end customers switching for unauthorized and authorized scenarios

3P decisions in both the unauthorized and the authorized scenarios. In the unauthorized scenario (if the OEM does not offer such a program or the 3P does not accept one), the model (Problem 4) consists of one OEM selling new products and one U3P selling refurbished products. Under an authorization scenario, the A3P needs to solve Problem 6. The third party will pay a royalty fee to the OEM to participate in the authorization program.

Lemma 1 shows that in the constrained problem where the supply of remanufacturable product is limited ($0 \leq q_r^A \leq \delta q_n^A$), for every scenario $j \in \{U, A\}$, the 3P collects all available used products (full refurbishing) whenever the reusability rate is relatively low ($\delta \leq \delta_i^j$), or low-end market base is relatively high ($k \geq k_i^j$), or authorization fee is relatively low $g \leq \bar{g}$. In full refurbishing, the 3P collects every used product that is accessible or obtainable. This implies that they indeed gather all the available used items. Hence, the number of refurbished products produced and sold is $q_r^A = \delta q_n^A$. In this case, there is a reusability rate, market level, and authorization fee level, at which the 3P does full refurbishing. However, when the reusability rate is relatively high ($\delta > \delta_i^j$), or the low-end market base is relatively low ($k^j < k_i^j$), or the authorization fee us relatively high $g > \bar{g}$, the 3P only collect some available used products (partial refurbishing). The 3P gathers or acquires a portion of the used products that are accessible or available. This suggests that they do not collect all available used products, but rather a limited or specific subset of them. Hence, the number of refurbished products produced and sold is $q_r^A < \delta q_n^A$.

Lemma 1 *Let $j \in \{U, A\}$ represent the scenarios, that is, unauthorized (U) and authorized (A). For each j, the constraint $q_r^j \leq \delta q_n^j$ is binding if $\delta < \bar{\delta}^j$ or, equivalently, if $k^j > \bar{k}^j$ or, equivalently, if $g < \bar{g}$. Figure 5 illustrates the optimal decisions of the 3P and Appendix A provides the values $\bar{\delta}^j$, $\bar{k}^j$, and $\bar{g}$.*

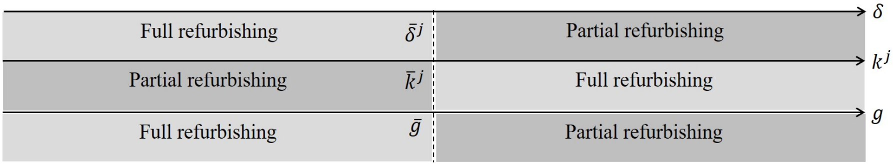


Fig. 5: Optimal decisions of the 3P for full and partial refurbishing for each scenario $j \in \{U, A\}$ with regard to thresholds $\bar{\delta}^j$, $\bar{k}^j$, and $\bar{g}$, as in Lemma 1

Proposition 2 *The optimal solutions for the 3P for both unauthorized and authorized scenarios are shown in Table 5, where $\bar{g} = p_n - c_r^A - \frac{2\delta Q_n}{d^A + \delta r^A}$. The optimal solutions for the 3P in unconstrained problem is the same as in the constrained problem with partial refurbishing.*

Proposition 3 *It is easy to show that the optimal authorization fee for the OEM is $g^* = \frac{d^A(p_n - c_r^A) + r^A w_n}{2d^A}$. There exists a threshold δ_t such that if $\delta \leq \delta_t$, $g^* \leq \bar{g}$. In this case, when the OEM set its authorization fee $g = g^*$, the 3P engage in full refurbishing. Otherwise, if $\delta > \delta_t$, $g^* > \bar{g}$ and the 3P engage in partial refurbishing while the OEM set its optimal fee (see, Table 6). Appendix A provides the values $\bar{\delta}_t$.*

Table 5: Third-party's decision

Partial refurbishing ($\delta > \bar{\delta}^j$ or $g > \bar{g}$)	Unauthorized (U)	Authorized (A)
$p_r^j = p_{r_1}^j$	$\frac{1}{2}(p_n + c_r^U)$	$\frac{1}{2}(p_n + c_g^A)$
q_r^j	$\frac{1}{2}d^U(p_n - c_r^U)$	$\frac{1}{2}d^A(p_n - c_g^A)$
Π_t^j	$\frac{1}{4}d^U(p_n - c_r^U)^2$	$\frac{1}{4}d^A\left(p_n - c_g^A\right)^2$
Full refurbishing ($\delta \leq \bar{\delta}^j$ or $g \leq \bar{g}$)		
$p_r^j = p_{c_1}^j > p_{r_1}^j$	$\frac{p_n d^U - \delta(Q_n - p_n r^U)}{d^U + \delta r^U}$	$\frac{p_n d^A - \delta(Q_n - p_n r^A)}{d^A + \delta r^A}$
q_r^j	$\frac{\delta Q_n d^U}{d^U + \delta r^U}$	$\frac{\delta Q_n d^A}{d^A + \delta r^A}$
Π_t^j	$\frac{\delta Q_n d^U((d^U + \delta r^U)(p_n - c_r^U) - \delta Q_n)}{(d^U + \delta r^U)^2}$	$\frac{\delta Q_n d^A((d^A + \delta r^A)(p_n - c_g^A) - \delta Q_n)}{(d^A + \delta r^A)^2}$

Table 6: OEM's decision

$\delta > \delta_t$ (or $g^* > \bar{g}$)	Unauthorized (U)	Authorized (A)
g	$-$	$g^* = \frac{d^A(p_n - c_r^A) + r^A w_n}{2d^A}$
q_n^j	$Q_n - \frac{1}{2}r^U(p_n - c_r^U)$	$Q_n - \frac{1}{2}r^A(p_n - c_g^A)$
Π_o^j	$w_n(Q_n - \frac{1}{2}r^U(p_n - c_r^U))$	$Q_n w_n + \frac{1}{2}(p_n - c_g^A)(gd^A - r^A w_n)$
$\delta \leq \delta_t$ (or $g^* \leq \bar{g}$)		
g	$-$	$g^* = \frac{d^A(p_n - c_r^A) + r^A w_n}{2d^A}$
q_n^j	$\frac{Q_n d^U}{d^U + \delta r^U}$	$\frac{Q_n d^A}{d^A + \delta r^A}$
Π_o^j	$\frac{Q_n w_n d^U}{d^U + \delta r^U}$	$\frac{(\delta g + w_n) Q_n d^A}{d^A + \delta r^A}$

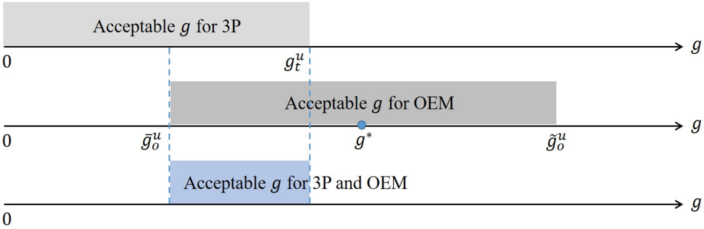
Proposition 2, identifies the 3P's optimal decision for each scenario. When there is a limited supply of remanufacturable product with full refurbishing, the authorization fee does not influence the optimal price of the refurbished products. In this case, the 3P collects and refurbishes all available used products. That is, the 3P does not change the price and the quantity of refurbished products if the authorization fee is in the range $g \in [0, \bar{g}]$. In the range of authorization fees, if there is a limited supply of the products with partial refurbishing, the 3P charges lower prices. However, if the authorization fee is relatively high, such that $g > \bar{g}$, the 3P decreases the number of refurbished products sold in the market and increases the price. In this case, the firm does not need to collect and refurbish all available used products. Moreover, a lower reusability rate (δ) leads the 3P to increase the refurbished product price for profitable refurbishing, generated by high profit margins. The analysis results for the constrained problem with partial refurbishing are also applicable to the unconstrained problem where the supply of remanufacturable products is not limited.

Proposition 3 identifies the OEM's optimal decision. Within the setting of a Stackleberg game, the OEM determines its optimal authorization fee g^* using the 3P's response function. A higher reusability rate (δ) leads the OEM to increase the authorization fee for profitable refurbishing authorization. On the other hand, a higher authorization fee leads the 3P to engage in partial refurbishing, generated by low profit margins. If the OEM set its optimal authorization fee, the 3P may prefer to not engage in authorization refurbishing due to the high fee. To explore this we show in Proposition 4 and Corollary 5 what the acceptable authorization fees can be for both the OEM and 3P in order obtain a win-win solution.

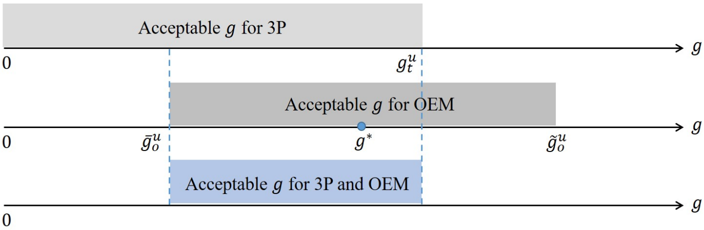
Proposition 4 *The condition for the 3P to engage in refurbishing authorization is $\Pi_t^A \geq \Pi_t^U$. The condition for the OEM to be profitable from the authorization scenario is $\Pi_o^A \geq \Pi_o^U$. The profit of the OEM is concave in the authorization fee. The acceptable authorization fees for the 3P and the OEM are $g \leq g_t^u$ and $\bar{g}_o^u \leq g \leq \tilde{g}_o^u$, respectively. Appendix A provides the values g_t^u, $\bar{g}_o^u$, and $\tilde{g}_o^u$. The optimal (most acceptable) authorization fee for the OEM is $g_o^{u*} = \frac{1}{2}(\bar{g}_o^u + \tilde{g}_o^u) = g^*$.*

Corollary 5 *The condition for the 3P to engage in refurbishing authorization when the OEM offers its optimal authorization fee g^* is $c_r^A \leq \bar{c}_r^A$ or $k^A \geq \bar{k}^A$. Otherwise, the 3P does not accept the authorization fee. Figure 6 illustrates the acceptable g for the 3P and OEM. Appendix A provides the values $\bar{c}_r^A$ and $\bar{k}^A$.*

By comparing the results of unauthorized (U) and authorized (A) scenarios, we determine whether the 3P should participate in the authorization program and whether the OEM should accept the 3P as an authorized refurbisher. Proposition 4 indicates the 3P will accept the authorization fee when it is



(a) $c_r^A > \bar{c}_r^A$ or $k^A < \bar{k}^A$



(b) $c_r^A \leq \bar{c}_r^A$ or $k^A \geq \bar{k}^A$

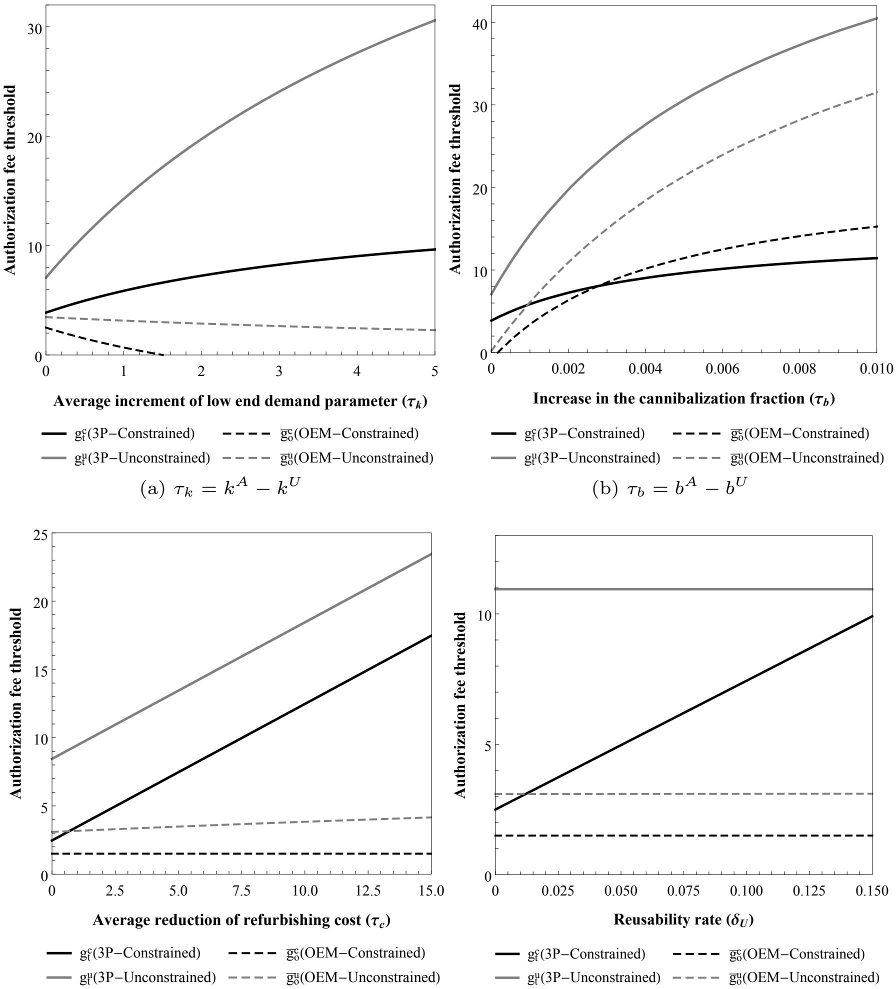
Fig. 6: Acceptable authorization fee for 3P and OEM when (a) 3P does not accept g^* and (b) 3P accept g^*

relatively low, such that the firm's profit increases following authorization. The OEM will obtain a higher profit from refurbishing authorization if the fee is relatively high. However, we observe that the profit of OEM is a concave curve with respect to authorization fee. Hence, the OEM does not always benefit from a higher authorization fee. The higher the fee, the more the 3P increases the price and decreases the number of refurbished products put in the market. The OEM should be aware of this effect: Authorization can be a win-win strategy for both the OEM and the 3P as long as the fees are acceptable for both firms. Corollary 5 indicates that lower refurbishing costs or higher market demand of low-end customers will widen the range of win-win solutions. Thus, the OEM can leverage this advantage by offering its optimal authorization fee. For instance, in Figure 6a, when the refurbishing cost is relatively high or the market demand of low-end customers is relatively low, the optimal authorization fee for the OEM is higher than the maximum acceptable authorization fee for the 3P. In this case, the optimal fee is outside the range of a win-win solution, and the 3P will not accept the authorized program offered by the OEM. On the other hand, in Figure 6b, when the refurbishing cost is relatively low or the market demand of low-end customers is relatively high, a win-win solution can be reached since the most acceptable authorization fee for the OEM falls within the range of acceptable fees for both parties.

Table 5 shows that if the two scenarios, U and A, use the same reusability rate δ, the quantity of refurbished products or the supply of used-products could be different, that is, $\delta q_n^U \neq \delta q_n^A$, because the new product quantity $q_n^j, j \in \{U, A\}$ is influenced by the refurbished product price and the cannibalization level, whereas the price is affected by potential market growth. To compare scenarios U and A, we assume the scenarios have the same upper boundary on the used product supply. Let $\delta_j, j \in \{U, A\}$ be the reusability rate of scenario j, and $\delta_A = \frac{\delta_U d^U d^A}{(d^U + \delta_U r^U)d^A - \delta_U d^U r^U}$, such that $\delta_U q_n^U = \delta_A q_n^A$. By comparing no authorization with authorization, we obtain an acceptable fee for the 3P and the OEM.

Proposition 6 *The acceptable authorization fees for the 3P and the OEM are $g \leq g_t^c$ and $g \geq \bar{g}_o^c$ respectively, where $\delta_j < \bar{\delta}^j$, $\forall j \in \{A, U\}$, $g_t^c = p_r^A - p_r^U + \tau_c$, and $\bar{g}_o^c = \frac{Q_n w_n (\tau_b k^U - \tau_k b^U)}{d^U d^A}$.*

Proposition 6 shows that in the constrained problem, authorization can be a win-win strategy for the OEM and the 3P, as long as there are some authorization fees such that $\bar{g}_o^c \leq g \leq g_t^c$. Because the two scenarios, U and A, have the same refurbished product quantity, the 3P engages in refurbishing authorization if the total benefits from the price differences and lower refurbishing cost are higher than the authorization fee. Therefore, higher potential market growth and lower refurbishing cost, which result from the 3P being authorized, increases the firm's intention to engage in authorization. However, the OEM may not offer refurbishing authorization if it increases cannibalization. When the used products supply is constrained, the OEM's profit is an increasing linear function of the authorization fee. The average increment of the low-end market base has a positive effect for the 3P, as well as for the OEM. Therefore, the higher the low-end market base, the higher the possibility firms can find win-win solutions.



(a) $\tau_k = k^A - k^U$ (b) $\tau_b = b^A - b^U$

(c) $\tau_c = c_r^U - c_r^A$ (d) $\delta_U\,(\delta_U q_n^U = \delta_A q_n^A)$

Fig. 7: Authorization fee thresholds for different parameters τ_k, τ_b, τ_c, and δ_U when $Q_n = 1000, p_n = 100, c_n = 70, c_r^U = 20, b^U = .001, k^U = 3, p_r^m = 30$.

To demonstrate the acceptable authorization fees for both OEM and 3P under varying circumstances, we present numerical simulations in Figures 7 and 8. The parameter values have been sourced from relevant literature, including Ferrer and Swaminathan (2006), Ovchinnikov (2011), and Ovchinnikov et al (2014). Figure 7 illustrates the acceptable authorization fee for both the OEM and the 3P for differing rates of market growth, cannibalization, refurbishing cost, and reusability. In Figure 7a, for both the constrained and unconstrained problems, the range of acceptable authorization fees is wider, because more low-end consumers purchase refurbished products. The authorization fee threshold for the 3P (maximum acceptable fee) and the OEM (minimum acceptable fee) in the constrained problem always is lower than in the unconstrained case. That is, the 3P prefers to accept authorization fees when the remanufacturable supply is large (see also Figures 7d and 7b). If the supply is constrained, the potential market growth that could be profitable for the 3P following authorization cannot be fully utilized. However, due to cannibalization, the OEM prefers to offer the refurbishing authorization to the 3P that has fewer refurbished products for sale or has high potential market growth from low-end customers. Yet the OEM also has great concerns about the increase in cannibalization following refurbishing authorization. Figure 7b shows that if the remanufacturable supply is constrained, there may not be a win-win solution when cannibalization is relatively high; the OEM will charge a high authorization fee, and the 3P cannot increase its minimum acceptable fee very much, because the firm can benefit only from the profit margin of its limited products. Figure 7c shows that the higher the average reduction of refurbishing cost, the higher the minimum acceptable fee of the 3P; it does not have a significant impact on the acceptable fee of the OEM. This result could be useful information for OEMs, because it widens the ranges of win-win solutions. Thus, the OEM can leverage this advantage by increasing the authorization fee.

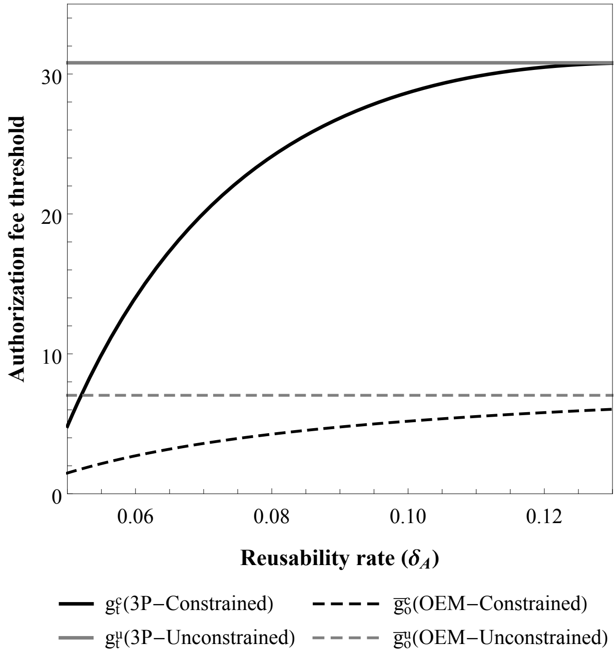


Fig. 8: Authorization fee thresholds for different δ_A when $Q_n = 1000, p_n = 100, c_n = 70, c_r^U = 20, b^U = .001, k^U = 3, p_r^m = 30, \delta_U = .05$ $(\delta_U q_n^U \leq \delta_A q_n^A)$.

Figure 8 illustrates the acceptable authorization fee for both the OEM and the 3P for differing reusability rates under the authorization scenario. In this case, the remanufacturable supply is constrained by $\delta_U q_n^U$. After being authorized, the 3P can access more used product supply, so the supply is still constrained with $\delta_U q_n^U \leq \delta_A q_n^A$ (parameter δ_A increases), or else the supply becomes unlimited. Figure 8 shows that as the reusability rate increases, the 3P increases its maximum acceptable fee. The increase is higher than the case of $\delta_U q_n^U = \delta_A q_n^A$ (see Figure 7d), in which the firm cannot sell more refurbished products even after being authorized. The OEM also increases its minimum acceptable authorization fee, because it faces an increased threat of cannibalization.

5 Conclusion

In this study, we focus on unauthorized and authorized refurbishing strategies of an OEM and a 3P. With the rapid growth of the refurbished market for electronic products, it is beneficial for OEMs to cooperate with 3Ps via authorization schemes; such schemes can boost OEMs' brand reputations, increase their sales, and strengthen consumer acceptance of A3P's refurbished products. We empirically characterize consumer behavior in complex settings, then use these insights to model and analyze optimal pricing policies. The higher the sellers' reputations, the higher the demand share for refurbished products.

Our empirical studies show that for low-brand valued products, there are customers who perceived low-priced refurbished products as being low quality and choose to purchase new products. As discounts increase, firms with lower brand value observe an inverted U-shaped cannibalization behavior because consumers start to become suspicious of the quality. However, this is only observed when the discounts are very high. Such large discounts are not observed in reality. Firms with a high brand image or high-quality products show linear cannibalization because the consumers trust the quality of the refurbished version of the product.

Our analytical results show that 3Ps accept authorization fees when the fees are relatively low, such that firms' profits increase following authorization, and OEMs obtain higher profits from refurbishing authorization if fees are relatively high. However, OEMs do not always benefit from higher authorization fees, because higher fees lead 3Ps to increase their prices, thereby decreasing the number of refurbished products they place on the market. Moreover, to reach authorization agreements, OEMs should not set their authorization fees too high.

If remanufacturable supplies are constrained, authorization fees do not influence optimal prices of refurbished products. In this case, 3Ps collect and refurbish all available used products. However, if authorization fees are relatively high, 3Ps do not need to collect and refurbish all available used products. Hence, the authorization fee eventually also impacts the share of the market that would get refurbished. The authorization fee threshold for 3Ps (i.e., maximum acceptable fee) and OEMs (i.e., minimum acceptable fee) in the constrained problem is always lower than in the unconstrained problem. 3Ps prefer to accept authorization fees when remanufacturable supplies are relatively large and OEMs prefer to offer refurbishing authorization to 3Ps with fewer refurbished products for sale. Hence, for an OEM their strategic decision on the authorization fee needs to be closely aligned with their estimate on the remanufacturable supplies. This is an important insight from our study that can inform OEMs to make better decisions. Finally, the larger the low-end market base, the greater the possibility that OEMs and 3Ps will reach win–win solutions. This could drive OEMs and 3Ps to further combine markets, such as maybe larger high-end markets in some countries with larger low-end markets in other countries. While we have not studied these effects specifically, our model could inform such strategies.

In general, with the global refurbishing market growing, and thousands of third party refurbishing companies active, OEMs need to decide on their authorization strategies. We see different practices with different OEMs. Our work contributes to the understanding of an authorization strategy, and demonstrates that smartly setting the authorization fee in relation to the available number of products in the refurbishing market, determines the adoption rate by third parties. Such responses need to be considered by OEMs.

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Appendix A Proofs for Third Party Refurbishing

Proof Proof of Lemma 1

Unauthorized scenario. we have $\frac{\partial^2 \Pi_t^U}{\partial p_r^2} = -2d^U$. Hence, Π_t^U is always concave in p_r^U. By solving $\frac{\partial \Pi_t^U}{\partial p_r^U} = 0$, we obtain $q_n^{U*} = \frac{Q_n(2-b^U(p_r^U - c_r^U))}{2}$ and $q_r^{U*} = \frac{d^U(p_n - c_r^U)}{2}$. The constraint is binding, i.e., $q_r^U > \delta q_n^U$, if $\delta < \bar{\delta}^U$ or equivalently $k > \bar{k}^U$, where $\bar{\delta}^U = \frac{d^U(p_n - c_r^U)}{2Q_n - r^U(p_n - c_r^U)}$ and $\bar{k}^U = \frac{2\delta Q_n}{p_n - c_r^U} - (\delta+1)r^U$. In this case, $q_r^{U*} = \delta q_n^U$ (full refurbishing). Hence, if $\delta \geq \bar{\delta}^U$ or $k \leq \bar{k}^U$, $q_r^{U*} < \delta q_n^U$ (partial refurbishing).

Authorized scenario. Using the same method as unauthorized scenario, by solving $\frac{\partial \Pi_t^A}{\partial p_r^A} = 0$, we obtain $q_n^{A*} = \frac{1}{2}\left(2Q_n - r^A\left(p_n - c_g^A\right)\right)$ and $q_r^{A*} = \frac{1}{2}d^A\left(p_n - c_g^A\right)$. The constraint is binding, i.e., $q_r^A > \delta q_n^A$, if $\delta < \bar{\delta}^A$ or equivalently $k^A > \bar{k}^A$ or equivalently $g < \bar{g}$, where $\bar{\delta}^A = \frac{d^A(p_n - c_g^A)}{2Q_n - r^A(p_n - c_g^A)}$, $\bar{k}^A = \frac{2\delta Q_n}{p_n - c_g^A} - (\delta+1)r^A$, and $\bar{g} = p_n - c_r^A - \frac{2\delta Q_n}{d^A + \delta r^A}$. In this case, $q_r^{A*} = \delta q_n^A$ (full refurbishing). Hence, if $\delta \geq \bar{\delta}^A$ or $k^A \leq \bar{k}^A$ or $g \geq \bar{g}$, $q_r^{A*} < \delta q_n^A$ (partial refurbishing). □

Proof Proof of Proposition 2

Unauthorized scenario. Recall the proof of Lemma 1. By using Karush-Kuhn-Tucker (KKT) approach, if $\delta > \bar{\delta}^U$ (partial refurbishing), we obtain the optimal price $p_r^{U*} = p_{r_1}^U = \frac{p_n + c_r^U}{2}$. Hence, the refurbished product quantity $q_r^{U^*} = \frac{d^U(p_n - c_r^U)}{2}$ and the third-party's profit $\Pi_t^{U^*} = \frac{d^U(p_n - c_r^U)^2}{4}$. If $\delta \leq \bar{\delta}^U$ (full refurbishing), we obtain the optimal price $p_r^{U*} = p_{c_1}^U = \frac{p_n d^U - \delta(Q_n - p_n r^U)}{d^U + \delta r^U} > p_{r_1}^U$. Hence, the refurbished product quantity $q_r^{U^*} = \frac{\delta Q_n d^U}{d^U + \delta r^U}$ and the third-party's profit $\Pi_t^{U^*} = \frac{\delta Q_n d^U((d^U + \delta r^U)(p_n - c_r^U) - \delta Q_n)}{(d^U + \delta r^U)^2}$.

Authorized scenario. Using the same method as unauthorized scenario, if $\delta > \bar{\delta}^A$ or $g > \bar{g}$ (partial refurbishing), we obtain the optimal price $p_r^{A*} = p_{r_1}^A = \frac{1}{2}(p_n + c_g^A)$. Hence, the refurbished product quantity $q_r^{A*} = \frac{1}{2}d^A(p_n - c_g^A)$ and the third-party's profit $\Pi_t^{A*} = \frac{1}{4}d^A\left(p_n - c_g^A\right)^2$. if $\delta \leq \bar{\delta}^A$ or $g \leq \bar{g}$ (full refurbishing), we obtain the optimal price $p_r^{A*} = p_{c_1}^A = \frac{p_n d^A - \delta(Q_n - p_n r^A)}{d^A + \delta r^A} > p_{r_1}^A$. Hence, the refurbished product quantity $q_r^{A*} = \frac{\delta Q_n d^A}{d^A+\delta r^A}$ and the third-party's profit $\Pi_t^{A*} = \frac{\delta Q_n d^A\left((d^A+\delta r^A)(p_n-c_g^A)-\delta Q_n\right)}{(d^A+\delta r^A)^2}$. □

Proof Proof of Proposition 3

In the OEM-Stackelberg game model, solving Problem 6 we obtain the 3P's reaction function $p_r^A(g) = \frac{1}{2}\left(c_r^A + g + p_n\right)$. Substituting p_r^A into Problem 5 and solving it we obtain $g^* = \frac{d^A(p_n-c_r^A)+r^A w_n}{2d^A}$. Let $\delta_t = \frac{d^A\left(r^A w_n - d^A(3c_r^A+p_n)\right)}{d^A(r^A(3c_r^A+p_n)+4Q_n)-(r^A)^2 w_n}$. Solving $\delta \leq \delta_t$ for g^* yields $g^* \leq \bar{g}$. Recall the proof of Proposition 2. Since if $\delta > \delta_t$, $g^* > \bar{g}$, we have the new product quantity $q_n^A = Q_n - \frac{1}{2}r^A(p_n - c_g^A)$ and the OEM's profit $\Pi_o^A = Q_n w_n + \frac{1}{2}(p_n - c_g^A)(gd^A - r^A w_n)$. On the other hand since if $\delta \leq \delta_t$, $g^* \leq \bar{g}$, we have $q_n^A = \frac{Q_n d^A}{d^A+\delta r^A}$ and $\Pi_o^A = \frac{(\delta g + w_n)Q_n d^A}{d^A+\delta r^A}$. In unauthorized scenario, when the OEM does not engage in authorization refurbishing, if $\delta > \bar{\delta}^U$, we obtain $q_n^U = Q_n - \frac{1}{2}r^U(p_n - c_r^U)$ and $\Pi_o^U = w_n(Q_n - \frac{1}{2}r^U(p_n - c_r^U))$; where as if $\delta \leq \bar{\delta}^U$, $q_n^U = \frac{Q_n d^U}{d^U+\delta r^U}$ and $\Pi_o^U = \frac{Q_n w_n d^U}{d^U+\delta r^U}$. □

Proof Proof of Proposition 4

Solving $\Pi_t^A \geq \Pi_t^U$ for g yields $g \leq g_t^u$, where $g_t^u = p_n - c_r^A - \frac{\sqrt{d^U}(p_n-c_r^U)}{\sqrt{d^A}}$. Solving $\Pi_o^A \geq \Pi_o^U$ for g yields $\bar{g}_o^u \leq g \leq \tilde{g}_o^u$, where

$$\bar{g}_o^u = \frac{d^A\left(p_n - c_r^A\right) + r^A w_n - \sqrt{\left(r^A w_n - d^A\left(p_n - c_r^A\right)\right)^2 + 4d^A r^U w_n\left(p_n - c_r^U\right)}}{2d^A},$$
$$\tilde{g}_o^u = \frac{d^A\left(p_n - c_r^A\right) + r^A w_n + \sqrt{\left(r^A w_n - d^A\left(p_n - c_r^A\right)\right)^2 + 4d^A r^U w_n\left(p_n - c_r^U\right)}}{2d^A}.$$

From the above expressions, the most acceptable authorization fee for the OEM is $g_o^{u*} = \frac{1}{2}(\bar{g}_o^u + \tilde{g}_o^u) = \frac{d^A(p_n-c_r^A)+r^A w_n}{2d^A} = g^*$. □

Proof Proof of Corollary 5

Let $g_t^u = p_n - c_r^A - \frac{\sqrt{d^U}(p_n-c_r^U)}{\sqrt{d^A}}$ and $g^* = \frac{d^A(p_n-c_r^A)+r^A w_n}{2d^A}$. Solving $g_t^u < g^*$ for c_r^A yields $c_r^A > \bar{c}_r^A$, where $\bar{c}_r^A = \frac{2\sqrt{d^U}(c_r^U-p_n)}{\sqrt{d^A}} - \frac{r^A w_n}{d^A} + p_n$. Solving $g_t^u < g^*$ for k^A yields $k^A < \bar{k}^A$, where

$$\bar{k}^A = \frac{2\sqrt{d(p_n - c_r^U)^2(r^A w_n(p_n - c_r^A) + d(p_n - c_r^U)^2)} - (r^A(c_n - c_r^A)(p_n - c_r^A)) + 2d(p_n - c_r^U)^2}{(p_n - c_r^A)^2}.$$

□

Proof Proof of Proposition 6

Let $\delta_U < \bar{\delta}^U$, $\delta_A < \bar{\delta}^A$, $g_t^c = p_r^A - p_r^U + \tau_c$ and $\bar{g}_o^c = \frac{Q_n w_n(\tau_b k^U - \tau_k b^U)}{d^U d^A}$. Solving $\Pi_t^A \geq \Pi_t^U$ for g yields $g \leq g_t^c$. Solving $\Pi_o^A \geq \Pi_o^U$ for g yields $g \geq \bar{g}_o^c$. □

Appendix B Experimental Design and Queries

In general, the design of a DCE proceeds in the following steps: selection of attributes and levels; construction of the experimental design; and survey design (Botelho et al, 2018). In the experiment, respondents are presented with several choice tasks that vary in the level of the attributes. On each task, they are given a set of alternatives and are asked to choose the favorite one. The first stage of the study is to determine a suitable selection of attributes. In the selection of attributes, a broad review of refurbishing is conducted to identify factors that have significant influences for consumers in purchasing refurbished products.

We estimate the utility functions from the observed choices using the maximum likelihood estimation procedure, such that the probability of getting the observed choices is maximized, where U_{ijk} is the estimated utility of alternative i to respondent j in question k. The MNL model defines the utility as

$$U_{ijk} = V_{ijk} + \epsilon_{ijk} = \beta.X_{ijk} + \epsilon_{ijk},$$

for $i = 1, ..., I$, $j = 1, ..., J$, and $k = 1, ..., K$, where V_{ijk} is a systematic observed component, ϵ_{ijk} is an unobserved random component, X_{ijk} is a vector of observed attributes of alternative i, and β is a vector of the utility weight in the population, defined as the value consumers associate with each attribute in X_{ijk}. The probability that consumer j chooses alternative i in question k is logit and given by

$$P(i|X_{jk}) = \frac{exp(\beta.X_{ijk})}{\sum_{i=1}^{j} exp(\beta.X_{ijk})},$$

where X_{jk} is the vector of attributes of all alternatives $i = 1, ..., I$. In the MNL model, the error terms for the alternatives are independent and identically distributed as Gumbel variables, which implies that the unobserved utility components are uncorrelated and that all alternatives have the same variance. That is, the alternatives do not share any unobserved characteristics, and the error terms help determine the utility to the same extent for all alternatives. Thus, cross elasticity among all pairs of alternatives is identical. According to Adamowicz et al (1998), the probability ratios of choosing one alternative over another is not affected by the presence of additional alternatives in the choice set. Thus, the alternatives can be eliminated and introduced without reestimation (Train, 2009). In some cases, the utility function could be nonlinear, which can be represented by an inverted U-shaped parabola. For a certain price range, the utility function has a positive slope until it reaches a price threshold and changes to a negative slope. In other words, when the price is relatively low, the utility increases with price, which is used by respondents as a proxy for quality. The observed component is given by

$$U = \beta_p p + \beta_q p^2 + \sum \beta X,$$

where p is the attribute price, β_p is the price coefficient in the utility function, β_q is the coefficient of price^2, and X represents the product attributes except price. If $\beta_p < 0$ and $\beta_q > 0$, the indirect utility function becomes parabolic. Even if the parameter estimation is significant though, we cannot say an inverted U-shaped utility function exists. The position of price threshold should be observed carefully. The inverted U-shaped utility function does not exist when β_q is relatively small, such that the price threshold is lower than 0, or the discount threshold is higher than 100%. It also does not exist if the price threshold is relatively low, because a firm usually charges a refurbished product price higher than its refurbishing cost and takes a minimum profit margin.

The LC model is usually used when discrete heterogeneity is present in the population. Multiple homogeneous groups can be specified, with each group having its own choice behavior. We estimate the chance that a person belongs to a certain class. We intend to find whether any class has an inverted U-shaped utility in discount (price) and thus choose the model with two classes: a class with a linear price (discount) (class LD) and a class with a quadratic price (discount) (class QD). In class LD, the value of β_q is assumed to be 0, and higher utility is assigned to lower price (or higher discount). In contrast, we estimate parameter β_q in class QD. We group respondents with similar observed variable distributions into the same class. The two-class model has good interpretability, and by applying this model to all brands, the differences among classes become visible, and we can also observe the differences among brands.

To validate our experimentation procedure, we conducted two pilot tests. We conducted the first test with 41 undergraduate students at the Eindhoven University of Technology to obtain feedback and ensure the procedure was clear, complete, and realistic. We conducted the second test with 200 MTurk workers. On the basis of responses to the pilot studies, we rewrote the introduction and survey questions for the experiments to clarify the experimental settings better. Our study was restricted to workers based in the United States, and respondents were required to have at least 100 approved human intelligence tasks and have a good reputation (i.e., above 95% approval rating). We applied such sample restrictions to ensure high-quality data (Peer et al, 2014; Hauser and Schwarz, 2016). Each worker was paid $1. When an MTurk participant completes a task, the requester of the task can reject or approve the submission based on the credibility and reliability of the data provided by the worker.

Efficient design - choice sets

Choice situation	*refurba. condition*	*refurba. seller*	*refurba. discountreb*	*refurbb. condition*	*refurbb. seller*	*refurbb. discountreb*
1	3	3	0.05	1	1	0.5
2	1	2	0.9	3	2	0.4
3	1	2	0.7	3	2	0.2
4	2	2	0.4	2	2	0.9
5	3	1	0.3	1	2	0.8
6	1	1	0.05	3	3	0.5
7	1	1	0.5	3	3	0.05
8	3	3	0.8	1	1	0.3
9	3	2	0.6	1	2	0.1
10	2	3	0.4	2	1	0.9
11	1	1	0.6	3	3	0.1
12	2	1	0.9	2	3	0.4
13	3	2	0.8	1	2	0.3
14	2	3	0.5	2	1	0.05
15	1	2	0.1	3	1	0.6
16	2	1	0.2	2	3	0.7
17	2	2	0.3	2	2	0.8
18	3	1	0.2	2	3	0.7
19	3	3	0.7	1	1	0.2
20	2	3	0.1	3	1	0.6

Experimental queries and demographics

In the experiment, participants were assigned to only one brand, that is either Apple or Motorola.

Screen 1

The main objective of this research is to explore the price-level sensitivity for refurbished products under competitive setting involving refrubished and new products. Price-sensitivity measurement has been established as a useful tool for pricing managers. Participants will be asked to complete the survey. We will only collect and process data that is strictly necessary for running the research. Individual responses will not be shared with or disclosed to anyone outside the research team. However, we might use aggregated results from the collected data for scientific publications, presentations at conferences and workshops and other dissemination purposes.

Clicking on the "Agree" button indicates that you have read and understood the information provided, you voluntarily agree to participate in this study, your responses will be gathered to be used, stored and shared in the ways described above.

Screen 2

Before we continue, we want to give you a basic definition of a refurbished product.

Refurbished products are used items that customers have returned to the manufacturer because they have changed their minds or due to a defect. They can also be items or product demos with packaging damage in handling. To prepare a used item for resale, the manufacturer must put it through a detailed refurbishing process, including cleaning, running functionality tests, and repackaging. After a final check, the manufacturer can sell the product with a "remanufactured" or "refurbished" label. The refurbished products often come with warranties and sell for a good deal less than the new products. There are three possible conditions at which a refurbished product is available. An open box product is similar to new, except the item may be missing the original packaging, or in the original packaging but not sealed. A refurbished product has been inspected, cleaned, and repaired to meet manufacturer specifications and is in excellent condition. This item may or may not be in the original packaging. A Used condition product is fully operational and functions as intended, but may have some signs of cosmetic wear and has not been inspected by an authorized party. This item may be a store return that has been used.

A used product could be refurbished either by an original equipment manufacturer (OEM) refurbished product has been refurbished directly by the original manufacturer; an authorized 3P is a seller who has been approved and authorized by the OEM; an seller/unauthorized 3P is a seller who has not been approved by the OEM.

Screen 3

Assume that you are in need of a smartphone for your own use (not for sale or as a gift). You are offered 3 products: Used/Refurbished/Open Box smartphone, Used/Refurbished/Open Box smartphone, New smartphone. The three products have the same technical details: Internal memory: 64GB, Camera resolution: 12 MP, Battery: 1,821mAh Processor: Hexa core, Ram: 2GB, Security: Fingerprint sensor.

In the following questions, we are interested in knowing which product you would choose. There are 20 choice sets. In each choice set, you are offered different product conditions and prices. Please carefully choose a product that you would buy for yourself.

Attributes	Option A	Option B	Option C
Brand	Apple	Apple	Apple
Product Condition			
Seller Identity	Unauthorized Third-Party	Authorized Third-Party	Original Manufacturer (Apple Inc.)
Price (Discount)	$360 (40% discount)	$60 (90% discount)	$600
Your Choice	☐	☐	☐

Screen 4

Describe your feelings about the following statements.

	Strongly disagree (1)	(2)	(3)	(4)	(5)	(6)	(7) *Strongly agree*
For refurbished Apple smartphone, the price of a product is a good indicator of its quality.	☐	☐	☐	☐	☐	☐	☐
For refurbished Apple smartphone, the higher the price for a product, the higher the quality of the product.	☐	☐	☐	☐	☐	☐	☐
For refurbished Apple smartphone, I am not willing to go to extra effort to find lower price.	☐	☐	☐	☐	☐	☐	☐
For refurbished Apple smartphone, the time it takes to find low prices is usually not worth the effort.	☐	☐	☐	☐	☐	☐	☐
For refurbished Apple smartphone, I am not willing to go to extra effort to find lower price.	☐	☐	☐	☐	☐	☐	☐
For refurbished Apple smartphone, the time it takes to find low prices is usually not worth the effort.	☐	☐	☐	☐	☐	☐	☐
For refurbished Apple smartphone, I am very concerned about low prices, but I am equally concerned about product quality.	☐	☐	☐	☐	☐	☐	☐
For refurbished Apple smartphone, when purchasing a product, I always try to maximize the quality I get for the money I spend.	☐	☐	☐	☐	☐	☐	☐

Screen 5

Please indicate how knowledgeable you are of the following brands.

	Not at all knowledgeable (1)	(2)	(3)	(4)	(5) *Very knowledgeable*
Apple	☐	☐	☐	☐	☐

Please choose the number corresponding to your answer.

Screen 6

Demographic characteristics.

What is your gender

	Very low quality (1)	(2)	(3)	(4)	(5) *Very high quality*
New Apple smartphone is of	☐	☐	☐	☐	☐
Refurbished Apple smartphone is of	☐	☐	☐	☐	☐

☐ *Female* ☐ *Male* ☐ *Prefer not to answer*

What is your age

☐ < 18 ☐ $18 - 25$ ☐ $26 - 35$ ☐ $36 - 45$ ☐ $46 - 55$ ☐ > 55

What is your highest level of education

☐ *Some High School* ☐ *Bachelors degree*

☐ *High School Diploma* ☐ *Some graduate work*

☐ *Some university work* ☐ *Masters degree*

☐ *Associates degree* ☐ *Professional degree*

What is your annual household income

☐ $< \$12,000$ ☐ $\$50,000 - \$74,999$

☐ $\$12,000 - \$15,999$ ☐ $\$75,000 - \$99,999$

☐ $\$16,000 - \$24,999$ ☐ $> \$100,000$

☐ $\$25,000 - \$49,999$

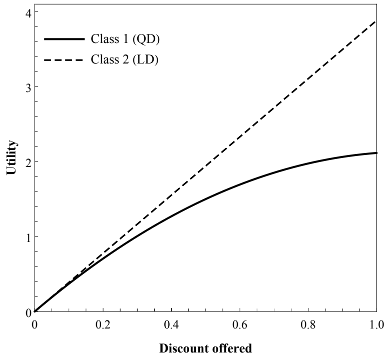
Appendix C Discrete Choice Experiment Output

We also present some statistics of interest for LC model (see Table C1 and Figure C1); as well as the complete experiment output.

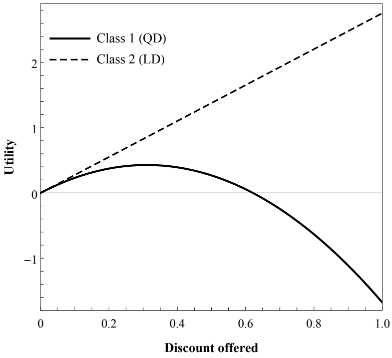
Table C1: Relative importance of attributes for the LC model

	Apple		Motorola	
Attributes	Class 1: QD (85.08%)	Class 2: LD (14.92%)	Class 1: QD (15.47%)	Class 2: LD (84.53%)
Discount	59.97%	74.17%	58.03%	64.11%
Product condition	08.55%	05.51%	12.96%	11.08%
Seller identity	31.48%	20.32%	29.01%	24.81%
Sum	100%	100%	100%	100%

Table C1 shows that class QD has lower discount sensitivity and has a higher seller and condition sensitivity than class LD in the two brands. Similar to the MNL model, the sensitivity of discount is higher than that of seller identity and



(a) Apple

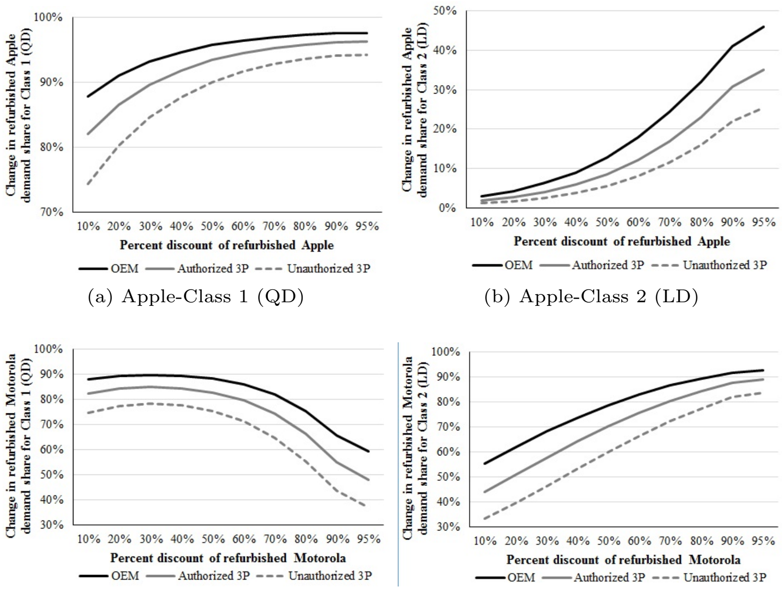


(b) Motorola

Fig. C1: Utility functions of discount offered for refurbished products in the LC model

product condition, and seller identity was preferred over product condition. Further, Figure C1 shows that although the quadratic parameter is significant for all brands, the quadratic discount can only be found in Motorola. In class QD, the part-worth utilities for the discount offered of refurbished Motorola starting decrease when the discount is around 30% of the full price of the new version. However, the percentage of customers who have this behavior is relatively low (15.47%). Around 84.53% of other customers associated with class LD has linear part-worth utilities. On the other hand, the part-worth utilities for the discount offered of refurbished Apple are linear in both class QD and LD.

Figure C2 illustrates the change in demand share of new and refurbished products from discount increases of the refurbished products for each brand and its classes. We observe that the higher the seller reputation, the higher the demand share of the refurbished products. For Motorola class QD, although the refurbished products are certified, i.e., sold by OEM or authorized third party, the demand share of the products is decreasing in discount after around 30% of the new product price. For Apple class QD, although the refurbished products are sold by unauthorized third party, the demand share of the products is always increasing in discount. The cross-discount elasticities for the LC model are illustrated in Figure C3 concerning brand and class. It can be seen in Figure C3c that in average, 1% increase in the discount of



(a) Apple-Class 1 (QD) (b) Apple-Class 2 (LD)

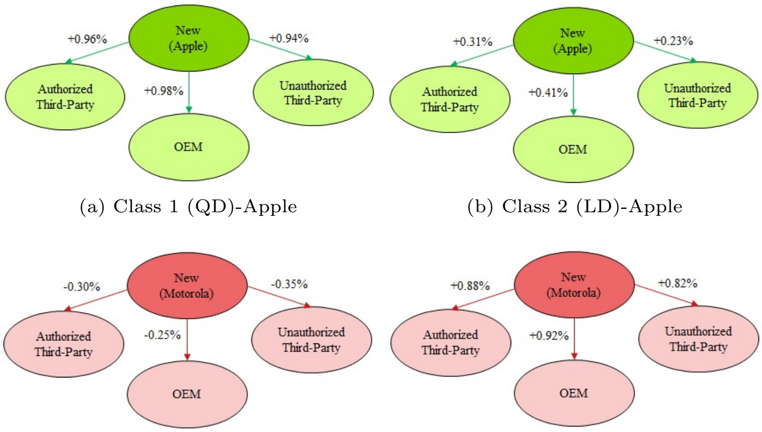
(c) Motorola-Class 1 (QD) (d) Motorola-Class 2 (LD)

Fig. C2: Change in demand share of refurbished products from discount increases of refurbished products in the LC model

OEM refurbished products decrease its market share by 0.25%. The lower the seller reputation, the higher the decrease level of the market share.

The results above indicate that for low-brand products, there are customers who perceived low-priced refurbished products as being low quality and choose to purchase new products. Firms with lower brand value will show the inverted U-shaped fraction because consumers will start to become suspicious of the quality as the discount gets larger. Firms with a high brand image or high-quality products will show a linear cannibalization fraction because the consumers will have trust in the refurbished version of the product.

The behavioral study was conducted using MTurk online panel offered by Amazon. The study was restricted to workers based in United States and at least they have 100 Human Intelligence Tasks (HITs) approved. Each worker was paid $1.



(a) Class 1 (QD)-Apple (b) Class 2 (LD)-Apple

(c) Class 1 (QD)-Motorola (d) Class 2 (LD)-Motorola

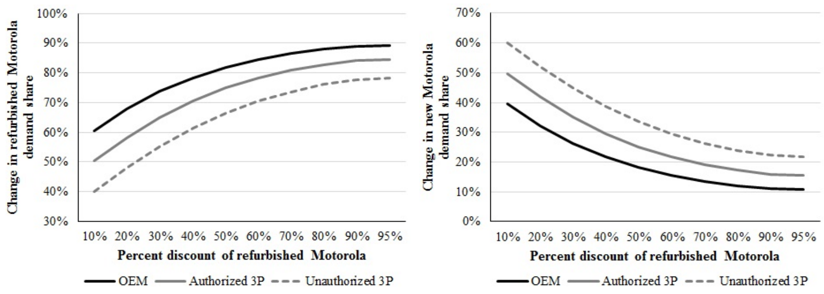
Fig. C3: Discount elasticity between new and refurbished products in the LC model

Table C2: Estimation results of MNL model.

Parameter	Value	Std. error	T-test	P-value	Robust std. error
Apple smartphone					
asc_new	1.569	0.185	8.468	0.000e+00	0.184
b_condition	0.123	0.036	3.426	6.119e-04	0.036
b_seller	0.444	0.038	11.774	0.000e+00	0.037
b_discountlinear	3.845	0.479	8.023	1.110e-15	0.477
b_discountquadratic	-1.706	0.417	-4.090	4.306e-05	0.416
LL	-1786.91	AIC	3583.818		
Rho bar square	0.208	BIC	3611.97		
Motorola smartphone					
asc_new	1.546	0.189	8.178	2.220e-16	0.189
b_condition	0.187	0.037	5.109	3.238e-07	0.037
b_seller	0.415	0.038	10.937	0.000e+00	0.038
b_discountlinear	3.670	0.485	7.567	3.819e-14	0.476
b_discountquadratic	-1.603	0.422	-3.794	1.485e-04	0.415
LL	-1712.40	AIC	3434.808		
Rho bar square	0.210	BIC	3462.763		

Table C3: Example of demand share of alternatives with MNL utility scores.

Attributes	Refurbished Smartphone	Utility	New Smartphone	Utility
Apple smartphone				
Product condition	Refurbished	0.247	New	
Seller identity	Authorized 3P	0.888	OEM	1.569
Price (discount)	$300 (50%)	1.496	$600	
Total		2.631		1.569
Corresponding exponent	13.888		4.802	
Demand share	74.31%		25.69%	
Motorola smartphone				
Product condition	Refurbished	0.375	New	
Seller identity	Authorized 3P	0.831	OEM	1.546
Price (discount)	$240 (50%)	1.434	$480	
Total		2.640		1.546
Corresponding exponent	14.013	4.693		
Demand share	74.91%		25.09%	



(a) Refurbished Apple (b) New Apple

Fig. C4: Change in demand share of refurbished and new products from discount increases of refurbished products (MNL model)

Table C4: Estimation results of LC model for Apple smartphone (iPhone).

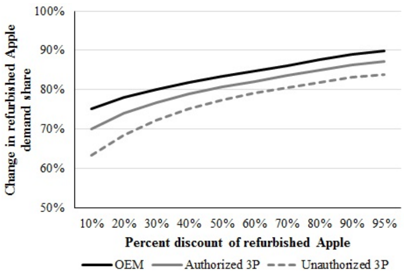
	Class 1 (85.1%)			Class 2 (14.9%)		
Parameter	Value	T-test	P-value	Value	T-test	P-value
asc_new	-	-	-	5.458	6.271	3.588e-10
b_condition	0.123	3.353	7.995e-04	0.123	3.353	7.995e-04
b_seller	0.452	11.551	0.00e+00	0.452	11.551	0.00e+00
b_discountlinear	3.883	7.563	3.930e-14	3.883	7.563	3.930e-14
b_discountquadratic	-1.769	-3.810	1.391e-04	-	-	-
LL	-1786.94	AIC	3585.872			
Rho bar square	0.208	BIC	3619.654			

Table C5: Estimation results of LC model for Motorola smartphone.

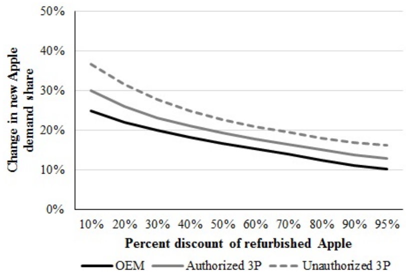
	Class 1 (15.5%)			Class 2 (84.5%)		
Parameter	Value	T-test	P-value	Value	T-test	P-value
asc_new	-	-	-	1.823	5.224	1.747e-07
b_condition	0.202	4.471	7.778e-06	0.202	4.471	7.778e-06
b_seller	0.453	7.828	4.885e-15	0.453	7.828	4.885e-15
b_discountlinear	2.755	7.329	2.316e-13	2.755	7.329	2.316e-13
b_discountquadratic	-4.435	-2.004	4.506e-02	-	-	-
LL	-1716.99	AIC	3445.998			
Rho bar square	0.208	BIC	3479.543			

Table C6: Example of demand share of alternatives with LC utility scores.

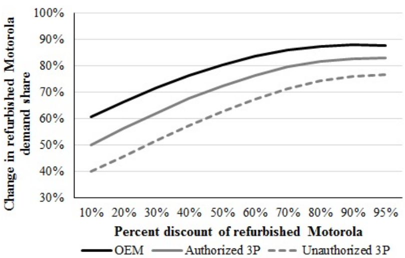
		Utility			Utility	
Attributes	Refurbished	Class 1	Class 2	New	Class 1	Class 2
Apple smartphone						
Product condition	Refurbished	0.245	0.245	New		
Seller identity	Authorized 3P	0.904	0.904	OEM	0.000	5.458
Price (discount)	$300 (50%)	1.500	1.942	$600		
Total		2.649	3.091		0.000	5.458
Corresponding exponent		14.140	21.999		1.000	234.628
Demand share per class		93.39%	08.57%		06.61%	91.43%
Class size		85.10%	14.90%		85.10%	14.90%
Demand share per product	80.75%	79.47%	01.28%	19.25%	05.63%	13.62%
Motorola smartphone						
Product condition	Refurbished	0.405	0.405	New		
Seller identity	Authorized 3P	0.906	0.906	OEM	0.000	1.823
Price (discount)	$240 (50%)	0.269	1.378	$480		
Total		1.580	2.689		0.000	1.823
Corresponding exponent		4.855	14.717		1.000	6.1904
Demand share per class		82.92%	70.39%		17.08%	29.61%
Class size		15.50%	84.50%		15.50%	84.50%
Demand share per product	72.33%	12.85%	59.48%	27.67%	02.65%	25.02%



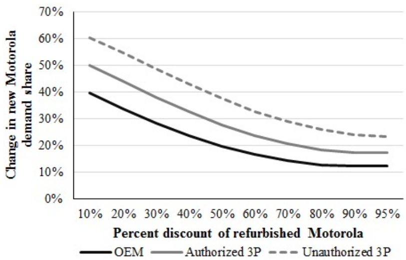
(a) Refurbished Apple



(b) New Apple



(c) Refurbished Motorola



(d) New Motorola

Fig. C5: Change in demand share of refurbished and new products from discount increases of refurbished products (LC model)