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Relicensing as a Secondary Market Strategy

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Secondary markets in the Information Technology (IT) industry, where used or refurbished equipment is traded, have been growing steadily. For Original Equipment Manufacturers (OEMs) in this industry, the importance of secondary markets has grown in parallel, not only as a source of revenue, but also because of their impact on these firms' competitive advantage and market strategy. Recent articles in the press have severely criticized some OEMs who are perceived to be actively trying to eliminate the secondary market for their products. Others have policies that enhance their secondary markets. The goal of this paper is to understand how an OEM's incentives and optimal strategies vis-à-vis the secondary market are shaped contingent on her relative competitive advantage, product characteristics and consumer preferences. The critical tradeoff that we examine is whether the indirect benefit from maintaining an active secondary market (the resale value effect) can outweigh the potentially negative effect of the sales of used products at the expense of new product sales (the cannibalization effect). To that end, we develop a durable good model where the OEM can directly affect the resale value of her product through a relicensing fee charged to the buyer of the refurbished equipment. We analyze the OEM's strategy in both the monopoly and the duopoly cases, characterize the optimal relicensing fee set by the OEM, and draw conclusions on the conditions that favor stimulating or deterring the secondary market.

Key words: Cannibalization, Secondary Market, Relicensing Fee, Remanufacturing, Closed-Loop Supply Chain

1. Introduction

Today, Original Equipment Manufacturers (OEMs) in the Information Technology (IT) industry often face difficult decisions when forming strategies involving secondary markets for their products. In the years before the dot-com bubble of the late 1990s, there was a limited secondary IT market.

Some reasons for this lack of demand for refurbished IT equipment included: 1) IT OEMs focused on their primary sales channels and discouraged customers from considering refurbished equipment; 2) buyers of IT equipment were leery of the quality level of a refurbished product; and 3) there was a lack of independent secondary market firms to refurbish, resell, and support IT equipment. Shortages of higher-end IT equipment such as servers and routers during the late 1990s however, led to unmet demand that was often satisfied by a new market of third-party IT equipment brokers and refurbishers[1]. In the years following, the dot-com bust resulted in a large surplus of barely used IT equipment for sale from companies who failed when the bubble burst. The availability of so much inexpensive used IT equipment led to significant price discounts compared to the price of new equipment, resulting in even more brokers and refurbishers entering the secondary market (Berinato 2002).

One of the lasting effects from the dot-com era is that major customers of IT equipment have started accepting refurbished IT equipment as a viable alternative to new equipment and a new body of IT refurbishers has entered the market to meet this demand. According to a 2002 survey of 187 IT executives in CIO magazine, 77 percent said they were purchasing secondary market equipment and 46 percent expected to increase their spending on refurbished equipment in the next year by an average of 15 percent (Berinato 2002). In another article, Computer Business Review highlights that "third-party companies have built $100+ million per year businesses in buying used computer equipment, refurbishing it, and selling or leasing it out to someone else" (CBRonline.com 2005). Given the size and growth of the secondary market, the days of ignoring it and only focusing on the sale of new products are over for all major IT OEMs. OEMs may either embrace the secondary market or try to eliminate it, but one thing is now evident, they must form strategies to respond to it.

[1] Third-party refurbishers do not manufacture their own products, but instead rebuild and reconfigure used OEM products that they buy from IT users who upgrade or no longer need those products. Unlike other markets such as the automotive market, potential customers in the used IT equipment market typically expect the equipment to be refurbished before purchasing; thus the vast majority of the sales in the IT secondary market are between refurbishers and the end-users rather than between the end-users themselves. Following industry usage, we will use the terms "refurbished" and "remanufactured" interchangeably in this paper; for a detailed definition of these terms, see Thierry et al. (1995).

Some of the major OEMs in the IT industry have not only embraced the existence of a secondary market, but also deploy it to obtain competitive advantage over their rivals. IBM and Hewlett Packard, for instance, create high resale values for their used equipment by facilitating the resale process and secondary use (e.g. charging small relicensing fees, offering maintenance and inspection) so that the original customers gain a higher net benefit from their new product purchases. Such a proactive, and in a sense cooperative, relationship with third-party brokers and refurbishers, however, is not a standard policy among all IT OEMs. An alternative strategy is to institute policies and fees that attempt to eliminate the secondary market. For example, Sun Microsystems (Sun), one of the leading firms in the IT server business, was "under fire for deliberately attempting to eliminate the secondary market for its machines worldwide through their new pricing and licensing schemes" (Marion 2004). Cisco is another company that requires each buyer of its refurbished equipment to pay high relicensing fees for the proprietary software that makes the equipment run.

The following excerpts, typical of the IT industry, shed some light on how the relicensing mechanism works. "Cisco adopts a policy of non-transferability of its software to protect its intellectual property rights." What this means is that owners of Cisco products are only allowed to transfer, resell, or re-lease used Cisco hardware and not the embedded software that runs on it. This practice, in effect, eliminates the secondary market and creates customer dissatisfaction. Cisco's response to this criticism was to institute relicensing fees, albeit significant: "As Cisco's installed base of equipment has grown to such large numbers over the years, our customers have become more interested in selling and leasing used Cisco equipment on the secondary market. In order to provide our valued customers and partners with this capability, Cisco is now setting up a program where companies who are interested in buying used equipment, may now purchase a new software license to do so" (Cisco.com 2007).

Despite such statements that a relicensing fee mechanism allows reselling refurbished equipment on the secondary market, many industry observers argue that some OEMs use unreasonably high relicensing fees as a means of limiting the secondary market. In the case of Sun, Marion (2004) highlights the fact that the relicensing fee is deliberately set so high that the overall cost of a unit of refurbished equipment, including hardware and software, reaches that of a new one: "In the end, the potential buyer for the refurbished equipment may have no choice but to return to Sun for a new product." He concludes by stressing another interesting facet of the problem: "End users need to know this and take action to adjust the Sun hardware values reflected on their respective balance sheets to account for the impact that Sun's actions, described above, will have on resale and residual values." In other words, users should be aware that Sun's practices result in very low resale values of used equipment and this information should be factored into their original purchase decision. In fact, many IT consulting companies (e.g. www.computereconomics.com) offer detailed forecasts regarding future resale values of used IT equipment, underlining the critical role of the resale value in the initial IT purchase decision.

From a research perspective, the discussion above raises the fundamental question addressed in this paper. Given the OEM's ability to interfere with the IT secondary market through pricing and relicensing schemes, is limiting this market or, conversely, encouraging its existence, a more profitable strategy? If one strategy is dominant over the other, the winner is currently not clear based on anecdotal evidence alone. Our goal is to understand how the OEM's incentives and optimal strategies are shaped contingent on costs, product characteristics, consumer preferences and the intensity of remanufacturing competition. Motivated by the industry articles concerning Sun, a company that has historically been considered the premium brand in the server market (Sun.com 2007), we also examine whether such a brand premium could justify an aggressive strategy vis-à-vis the secondary market.

We begin our analysis by studying the optimal strategy of an OEM that has a monopoly on the new product market, but faces future competition from a third-party entrant who purchases the used products from the OEM's customers, refurbishes them, and resells them in competition with the OEM's new products. The OEM collects a relicensing fee on every product sold by the entrant; and can effectively "shut down" the secondary market by charging a high enough fee. Our key finding is that it is suboptimal for the OEM to shut down the secondary market when consumers have a high willingness-to-pay for the refurbished product, even though this means the third party is more competitive. This seemingly counter-intuitive strategy is driven by the fact that in this range, not only can the OEM charge a higher relicensing fee, but she can also benefit from a stronger resale value effect. Moreover, we fully characterize the optimal relicensing and pricing scheme, and provide comparative statics results with respect to consumer and product characteristics.

We examine how the OEM's strategy changes as the number of the independent entrants increases. One may expect that as the secondary market becomes more competitive, the OEM is disadvantaged. Interestingly, we find that the OEM's profit is concave increasing in the number of third-party entrants. The reason is that the competition between the entrants increases the resale value and reduces the refurbished product price. The OEM benefits not only from the higher resale value and the additional relicensing revenues from the stronger demand for the refurbished product, but also from the fact that more first-period consumers resell their used product to buy her new product in the second period. We also find that if the OEM makes the strategic decision to participate in the secondary market herself, she no longer needs the third party to create a positive resale value for her product, and she uses the relicensing fee to price him out of the market.

We conclude by analyzing OEM strategies in a differentiated new product duopoly setting. Our numerical results show that the high-end OEM charges a higher relicensing fee than the low-end OEM, and the difference between their relicensing fees increases in the brand premium. While a stronger brand premium always translates into a larger market share in the primary market, as a result of this difference in the relicensing fees, the same is not true for the secondary market. In fact, we show that above a brand premium threshold, the high-end OEM's product makes up a smaller share of the secondary market. This result can help explain the strategy of some high-end OEMs who choose not to have a large presence in the secondary market despite the brand premium that they command.

2. Literature Review

A rapidly growing stream of literature on remanufacturing has focused on the competition between the OEM and independent refurbishers/remanufacturers (Majumder and Groenevelt 2001, Debo et al. 2005, Ferguson and Toktay 2006, Ferrer and Swaminathan 2006), or the role of OEM-initiated remanufacturing in primary market competition between OEMs (Heese et al. 2005, Atasu et al. 2008). We contribute to this literature in the following ways.

First, although the first set of papers provide a theoretical framework for analyzing the competition between the OEM and potential entrants that refurbish and sell the OEM's product, with the exception of an extension in Debo et al. (2005), they do not incorporate the effect of the resale value on the consumers' net utility from purchasing a new product[2]. As a result, they focus only on the cannibalization effect, and therefore, the existence of independent remanufacturers is always detrimental for the OEM's profit. We contribute to this stream by endogenizing the resale value on the secondary market, and more importantly, by linking it to the consumers' willingness-to-pay for a new product. Thus, competition from an independent refurbisher has both a positive (resale value effect) and a negative (cannibalization of new product sales) impact on the OEM's profit. We show that the resale value effect can dominate and the OEM can benefit from the existence of an entrant.

Second, Debo et al. (2005) find that as the number of remanufacturers increases (cannibalization increases), the OEM's profit decreases despite the positive resale value effect. With the relicensing fee mechanism, we show that a higher competitive intensity in the secondary market can benefit the OEM. This happens because the relicensing fee allows the OEM to indirectly influence the resale value effect and to directly benefit from the secondary market.

Third, we show that if the OEM decides to refurbish her own products in conjunction with the relicensing fee mechanism, she will dominate the secondary market by pricing out the third party. This is consistent with Heese et al. (2005), who show that an OEM with a cost or market advantage should enter the secondary market first to deter competing OEMs from doing so, Ferrer and Swaminathan (2006), who show that a higher remanufacturing cost savings means higher participation by the OEM in the secondary market, and Ferguson and Toktay (2006), who find that

[2] Heese et al. (2005) model the impact of the resale value as well, but in the context of primary market competition between OEMs while treating it as an exogenous effect on the secondary market.

as the entrant becomes more competitive and the cannibalization threat increases, the OEM should increase her efforts to deter the secondary market. If the OEM makes a strategic determination not to participate in the refurbished product market, however, then she should pursue the diametrically opposed strategy of supporting the secondary market, especially when the refurbished product is attractive to the consumers.

While the idea that a secondary market can benefit the OEM is relatively new in the remanufacturing literature, it is well established in the durable goods literature, a thorough review of which can be found in Waldman (2003). Motivated by the market for diamonds, Miller (1974) argues that "the buyer of a newly produced diamond pays a price consistent with what the diamond can be sold for to others including members of later generations" and thus "the initial price captures the present value of all subsequent transactions." This argument is also stressed by Benjamin and Kormendi (1974), Liebowitz (1982), Rust (1986), and Levinthal and Purohit (1989), who all argue that whether or not a monopolist has the incentive to eliminate the secondary market is not clear-cut. A limitation of these papers is the assumption that the demand side is modeled by a representative consumer (homogeneous consumer preferences). Anderson and Ginsburgh (1994) argue that in such models, the size of the second-hand market is indeterminate since the representative consumer buys both new goods and used goods each period and essentially sells the used good to herself. By introducing a model in which consumers have heterogeneous tastes, they show that the existence of a secondary market enables the monopolist to achieve price discrimination between high and low valuation consumers who buy new and used products, respectively.

Models allowing consumers to have heterogeneous tastes are refined in further research by Waldman (1996, 1997), Desai and Purohit (1998), Hendel and Lizzeri (1999) and Desai et al. (2004, 2007). Waldman (1996) employs the seminal Mussa and Rosen (1978) analysis of market segmentation and product-line pricing to allow consumers to vary in their valuations of quality. His main result is that because of the substitution effect between new and used products, the price at which old units trade on the secondary market constrains the price that the monopolist can charge for the new units. Therefore, he demonstrates that the monopolist may have an incentive to "shut down" the market by reducing durability to "sufficiently low" values. In a follow-up paper, Waldman (1997) demonstrates that leasing versus selling can be used to eliminate the secondary market, and argues that this motivation might have been the primary reason for many prominent anti-trust leasing cases (United Shoe, IBM, Xerox). Hendel and Lizzeri (1999) study leasing and selling strategies under secondary markets when durability is endogenous and the OEM can either allow a fully functioning secondary market (perfectly competitive with no restrictions) or shut down the secondary market completely. They show conditions where the OEM would not want to shut down the secondary market but prefers reducing the durability instead. Finally, Desai and Purohit (1998) and Desai et al. (2004, 2007) include the discounted resale price (resulting from perfect competition in the second period) in the consumer's first-period valuation of the new product, but their primary focus is on evaluating leasing versus selling, solving the time-consistency problem, or evaluating the impact of demand uncertainty, respectively.

We contribute to this literature on an OEM's incentive to interfere with the secondary market along the following dimensions. First, we introduce one more mechanism to this literature – imposing a relicensing fee – and are the first to capture the strategic implications of this widespread mechanism. Unlike previously explored mechanisms that require the OEM to make modifications to her product or market strategies, the relicensing fee mechanism is "costless" in that the OEM can set the fee as high as needed to deter the entrants without any direct repercussions. We show that nevertheless, the OEM should not shut down the secondary market under a wide range of conditions. By treating the relicensing fee as a continuous decision variable, we avoid restricting the OEM to either fully supporting or completely shutting down the secondary market (e.g. as in Hendel and Lizzeri 1999).

Second, we analyze the relicensing fee strategy in depth, by modeling operational elements such as production cost and refurbishing cost, by making a distinction between the inherent durability of the product and the value to the customer after refurbishing, by varying the level of competitive intensity on the secondary market, and by allowing competition in the primary market. We highlight some of these elements below.

We relax the common assumption of perfect competition in the secondary market and allow for a profit-maximizing entrant to collect and refurbish the used products (in the durable goods literature, consumers are allowed to sell the used product to each other, creating a perfectly competitive secondary market, and refurbishing cost is not modeled). The value offered to the consumers for the used product by the entrant is determined as his optimal response to the OEM's decisions. Thus, the purchase price for used units and the prices charged to consumers for new and refurbished products arise as the equilibrium of the game between the OEM and the entrant. This allows us to examine the impact of the production and refurbishing costs on the OEM's strategy.

In an extension, we also relax the assumption of a monopolist OEM by allowing vertically differentiated new products to compete in the primary market. To our knowledge, we are the first to model differentiated new and refurbished products competing in both the primary and secondary markets. We find that the high-end OEM charges a higher relicensing fee than the low-end OEM and that the difference between relicensing fees can be significant. Yet, whether a high-end or a low-end OEM has a greater secondary market depends on the market conditions and the relative brand differential between the two OEMs.

We conclude by highlighting a contribution at the intersection of the remanufacturing and durable goods literatures. Prior work on durable goods theory assumes that consumers trade among each other, selling the (depreciated) used product as is. In contrast, prior work on remanufacturing assumes that a used product provides no utility unless it is refurbished. Our model captures both aspects, where the product depreciates with use, but it can be refurbished by an entrant to offer a higher utility than if it is sold as is. Consequently, ours is the first paper that provides a complete characterization of the OEM's optimal strategy jointly along the dimensions of inherent product durability and the value provided by the remanufacturing process. As our analysis reveals, although both effects reduce the demand for new products in the second period, their role in determining the equilibrium can be diametrically opposite. For example, the equilibrium relicensing fee decreases in the durability of the product, but increases in the value that the customer obtains from the refurbished product. As explained in detail later, the difference stems from the way in which these two features affect the resale value of the product.

3. Key Assumptions and Notation

Our baseline analysis assumes the OEM holds a monopoly in the new product market. We develop a two-period model. In the first period, the OEM sells new products; these products depreciate over time. In the second period, the OEM may again sell new products, and there is a third-party entrant who may refurbish and resell used products it buys from the OEM's first-period customers. Thus, in the second period, the OEM's new product sales face competition from the refurbished products offered by the entrant. At the same time, the OEM generates relicensing fee revenues from the refurbished products. Our goal is to examine the OEM's relicensing fee strategy in the face of future competition from refurbished products. We make the following assumptions that build on assumptions commonly used in the durable goods literature (e.g. Desai and Purohit 1998):

Assumption 1. *Consumers are heterogeneous in willingness-to-pay.*

We assume that consumer types are distributed uniformly in the interval $[0,1]$, where a consumer of type $\theta \in [0,1]$ has a willingness-to-pay of θ for a new product. The market size is normalized to 1. In any period, each consumer uses at most one unit.

Assumption 2. *The product depreciates with use.*

The rate of depreciation of a product depends on its durability, which is parametrized by δ. Thus, if the consumer type θ who bought a new product in the first period continues to use that product in the second period, the utility he obtains in that period is $\delta\theta$. We take $\delta < 1$, such that all else being equal, a consumer prefers a new product to a used one.

Assumption 3. *Each consumer's willingness-to-pay for the refurbished product is less than that for the new product, but more than that for the used product.*

Empirical evidence for lower consumer valuation of remanufactured products is offered in Guide and Li (2007), and Subramanian and Subramanyam (2009). This perspective is also reflected in a number of articles in the practitioner literature (Hauser and Lund 2003, Kandra 2002). To model this, we assume that a consumer with a willingness-to-pay θ for the new product has a willingness-to-pay $\delta_r\theta$ for the refurbished one, where $\delta_r < 1$. Since refurbishing involves software updates, the replacement of wearable parts, cleaning and testing, the relative utility that a customer would obtain from using a refurbished product is higher than if he just kept using the product that he had purchased in the first period. We capture this by assuming $\delta < \delta_r$. This is a generalization relative to the majority of remanufacturing papers that take $\delta = 0$ such that the product's useful life (in the absence of being refurbished) is effectively only one period (Majumder and Groenevelt 2001, Ray et al. 2005, Ferrer and Swaminathan 2006, Ferguson and Toktay 2006, and Atasu et al. 2008).

Assumption 4. *Consumers do not sell their used products directly to each other.*

This assumption reflects the current practice in the used IT market where most used equipment, before it can be resold, requires testing, software updates and the replacement of wearable parts that the consumers do not have the technical capability to perform. Thus, we assume that consumers cannot sell their used products directly to each other. Instead, a third-party refurbisher buys used products from first-period consumers at a unit price s, and enters the market in the second period by refurbishing and reselling these products. The unit refurbishing cost, denoted by c_r, is less than the unit production cost for the new product, c. The higher the resale value s, the larger the consumer segment willing to sell their used product to the entrant. When the supply of used products exceeds the volume the entrant is willing to buy (this happens only with $s^* = 0$ in equilibrium), we assume that consumers can replace their used product with a new one (without selling the used product to the entrant) if doing so brings them higher net utility than continuing to use it.

Assumption 5. *Consumers are strategic.*

There is empirical evidence that IT consumers are strategic in their purchasing behavior (Song and Chintagunta 2003, Nair 2007, Plambeck and Wang 2006). Accordingly, we assume that consumers take into account the future resale value, s, of the product in making their purchase decisions. This is facilitated in practice by the existence of IT consulting companies that offer resale value forecasts and it is consistent with the durable goods literature. Our equilibrium characterization is based on rational expectations of consumers about future prices.

Assumption 6. *The OEM charges a relicensing fee to any consumer who purchases a refurbished product.*

The establishment of a relicensing fee, typically called a Digital License Agreement (DLA), has been widely employed by OEMs as a means of protecting their intellectual property rights. A DLA allows a consumer to re-install the necessary software for the equipment to operate and thus, a refurbished product is of no use without it. The unit relicensing fee, denoted by h, constitutes an important element of our model since it affects the resale value offered by the entrant which is taken into account by strategic consumers of new products. In particular, the net utility that each consumer derives from purchasing a refurbished product is given by the difference of their willingness-to-pay and the product's price plus the relicensing fee.

Assumption 7. *The entrant decides on his actions after observing the OEM's pricing and relicensing scheme.*

This sequence is consistent with practice: The price of the OEM's new products is considered one of the most critical determinants of whether third-party entrants will choose to refurbish and market that OEM's products or not. Moreover, knowledge of the OEM's relicensing policy is essential as the relicensing fee plays a key role in the demand for the refurbished product. Thus, we assume that the entrant determines the resale value, s, and the price of the refurbished product, p_r, after observing the pricing (first- and second-period prices for the new product, p_1 and p_2) and relicensing fee (h) decisions of the OEM.

Assumption 8. *In the second period, the OEM introduces a new product that is technologically equivalent or superior to the one introduced in the first period.*

The IT industry is characterized by rapid technological change. It is typical for an OEM to introduce an improved version of her existing product not long after the original product introduction. For instance, an upgraded version might have a faster Central Process Unit (CPU) or bigger memory. To capture the increased consumer willingness-to-pay for the new product due to this technology improvement, we assume that a consumer with a willingness-to-pay θ for the new product in the first-period has a willingness-to-pay $\alpha\theta$, where $\alpha \geq 1$, for a new product in the second period.

4. Analysis: Monopoly in the New Product Market

In this section, we analyze the model with a single OEM who sells a new product in both periods and charges a relicensing fee for refurbished products that are acquired, refurbished and resold by a third party in the second period. In Section 4.1, we provide a complete characterization of the equilibrium based on numerical analysis. In Section 4.2, we focus on the market configuration where all market segments exist in equilibrium and provide analytical results along the following dimensions: i) We study the effect of consumer preferences and product characteristics on the OEM's relicensing strategy and the size of the secondary market; and ii) we study the effect of competition on the secondary market by modeling multiple entrants and OEM refurbishing.

4.1. Characterization of the equilibrium

Since consumers are strategic and first-period consumers have the option to continue using their products, we derive the demand functions based on two-period consumer strategies (see for example Desai and Purohit 1998). In particular, the consumer state space is divided into the following segments: (i) Consumers who buy a new product in the first period and replace it with a new product in the second period (segment *nn* of size q_{nn}); (ii) consumers who buy a new product in the first period and continue using it in the second period (segment *nu* of size q_{nu}); (iii) consumers who do not buy in the first period, but buy a new product in the second period (segment *on* of size q_{on}); iv) consumers who do not buy in the first period, but buy a refurbished product in the second period (segment *or* of size q_{or}). In this paper, we assume that $\alpha < 1 + \delta$; otherwise the one-period utility from the improved product would be larger than the combined first- and second-period utility that a consumer would derive from a first-period purchase (in which case the *on* segment grows rapidly at the expense of all the other segments).

We solve the problem by backward induction, starting with the third party's optimization problem and assuming rational expectations on the part of the consumers. Letting Π_e denote the third party's profit, we can formulate the third party's problem as follows for given p_1, p_2 and h:

$$Max_{p_r,s}\ \Pi_e(p_r,s) = (p_r - c_r)q_{or} - sq_{nn}$$

$$\text{s.t.}\quad q_{or} \le q_{nn}\ \ q_{or} \ge 0\ \ s \ge 0$$

where the constraint $q_{or} \le q_{nn}$ ensures that the sales quantity of refurbished products is no greater than the number of units that can be collected from the consumers.

The OEM's problem is to maximize the total first- and second-period profits with respect to p_1, p_2 and h, taking into account the third party's best response function and the consumers' two-period strategies. To obtain the subgame-perfect Nash equilibrium, we first solve the OEM's second-period problem (i.e., we determine p_2^* and h^*), and then solve the first-period problem (i.e., we determine p_1^*). The OEM's second-period optimization problem is

$$Max_{p_2,h}\ \Pi_2(p_2,h|p_1) = Max_{p_2,h}(p_2 - c)(q_{nn} + q_{on}) + hq_{or}$$

$$\text{s.t.}\quad q_{nn}(p_2,h|p_1) \ge 0,\ q_{nu}(p_2,h|p_1) \ge 0,\ q_{on}(p_2,h|p_1) \ge 0,\ h \ge 0,$$

where the expressions for all quantities take into account the entrant's best response p_r^* and s^*.

Let $p_2^*(p_1)$ and $h^*(p_1)$ be the optimal values of the above maximization problem. The OEM's first-period optimization problem is

$$Max_{p_1}\ \Pi_1(p_1) + \Pi_2^*(p_1) = (p_1 - c)(q_{nn} + q_{nu}) + \Pi_2^*(p_1)$$

$$\text{s.t.}\quad q_{nn}(p_1) \ge 0,\ q_{nu}(p_1) \ge 0,\ q_{on}(p_1) \ge 0.$$

In the previous literature, constraints are not explicitly dealt with under the implicit assumption that the focus is on the parameter region where all segment sizes are positive and all constraints are non-binding. In this section, we provide a complete characterization of the Stackelberg equilibrium for any parameter combination $(\alpha, \delta_r, \delta, c, c_r)$, including those where some of these segments do not exist in equilibrium. Due to the complexity of the problem (OEM with three decision variables, entrant with two decision variables, two-period consumer strategies), we can only achieve this numerically. Figure 1 and Table 1 characterize the equilibrium solution in the (δ_r, δ) space for $\alpha = 1.25, c = 0.5$, and $c_r = 0.2$[3]. In Section 4.2, we present analytical results for the market equilibrium where q_{nn}^*, q_{nu}^*, q_{on}^* and q_{or}^* are all positive.

[3] Similar graphs were developed for every combination of the parameter values $\alpha \in [1, 1.5]$, $c \in [0.1, 0.9]$, and $c_r \in [0.1, c]$

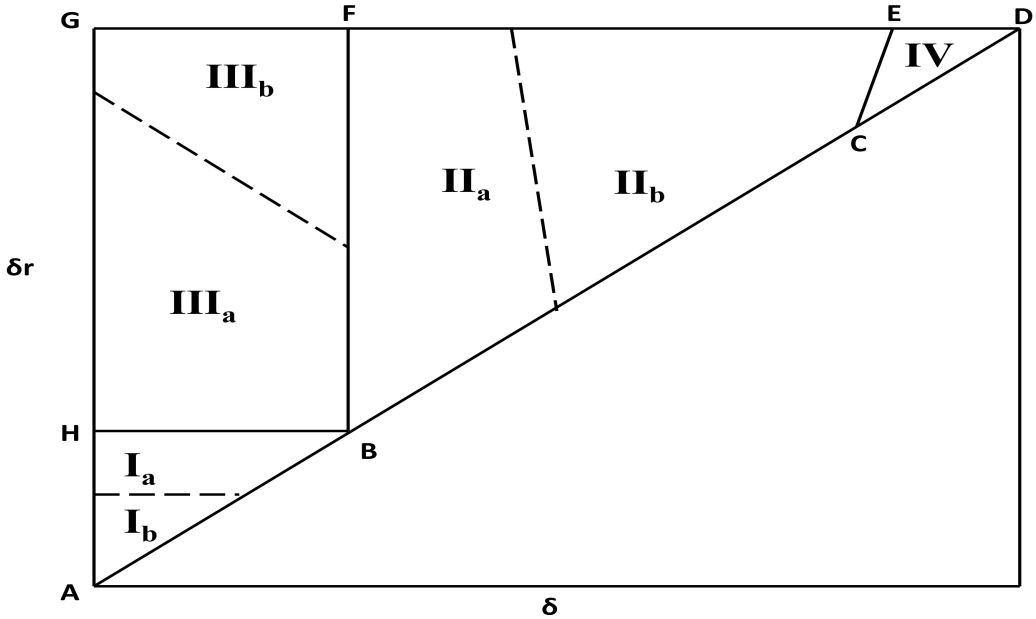


Figure 1 OEM's second-period optimal strategy for α=1.25, c=0.5, and c_r=0.2.

Region	Characteristics of the second period	Market Segments in Equilibrium
I	Only new products are used	$q^*_{nn} > 0, q^*_{nu} = 0, q^*_{on} > 0, q^*_{or} = 0$
II	New, used and refurbished products coexist	$q^*_{nn} > 0, q^*_{nu} > 0, q^*_{on} > 0, q^*_{or} > 0$
III	Only new or refurbished products are used	$q^*_{nn} > 0, q^*_{nu} = 0, q^*_{on} > 0, q^*_{or} > 0$
IV	Only new and used products coexist	$q^*_{nn} = 0, q^*_{nu} > 0, q^*_{on} > 0, q^*_{or} = 0$

Table 1 In region I (defined by the points ABH), the third party cannot profitably refurbish, with $h^* > 0$ in region I_a (the OEM uses the relicensing fee to price out the third party) and $h^* = 0$ in I_b (refurbishing is unprofitable even without a relicensing fee). In regions II and III, defined by the points BCEF and HBFG respectively, the OEM sets $h^* > 0$, but allows the third party to enter the market. In region II, segments nn, nu, on and or are positive. In region II_a, $s^* = 0$, while in region II_b, $s^* > 0$. In region III, the third-party also procures used products on the market for free ($s^* = 0$) and refurbishes them. Lastly, in region IV (defined by the points CDE), only q^*_{nu} and q^*_{on} are positive; all first-period customers continue using their products in the second period so no secondary market exists.

Observation 1: *Unless the product's durability is very high, there exists a threshold value $\widetilde{\delta_r}(\delta)$ such that for $\delta_r > \widetilde{\delta_r}(\delta)$, it is not optimal for the OEM to eliminate the secondary market ($q^*_{or} > 0$)*

(discretized in increments of 0.1). Our observations suggest that the overall structure of the region graph is robust, with the exception that for sufficiently low values of α, a new market configuration where all but the segment *on* are positive appears in equilibrium. A brief discussion on how the regions change with respect to α, c, and c_r is provided at the end of this section.

(regions II and III).

The line segments HB, BC, and CE define the threshold $\widetilde{\delta_r}(\delta)$ above which there is an active secondary market. Observation 1 may appear counter-intuitive at first glance: As δ_r increases, the third party becomes more competitive in relation to the OEM, but it is only when δ_r is large enough that the OEM chooses not to eliminate the secondary market! The result is driven by the double benefit that the OEM obtains from the secondary market: the resale value effect and relicensing fee revenues. At high values of willingness-to-pay for a refurbished product, these benefits outweigh the negative impact of cannibalization despite the fact that this is where the entrant poses the most competition to the OEM. But it is precisely because entry is more desirable for the third-party refurbisher that he offers a high resale value to first-period customers, which benefits the OEM. This result is counter to the common perception of many OEMs that competition from a third-party refurbisher is always detrimental to their profits. Observation 1 demonstrates that on the contrary, it is possible for the OEM to co-opt the third party into her business strategy by using the relicensing fee strategically.

Observation 2: *There is a threshold value $\widetilde{\delta_r}'(\delta)$ (dashed-line in Region I) such that for $\widetilde{\delta_r}' < \delta_r < \widetilde{\delta_r}$, the OEM charges a positive relicensing fee ($h^* > 0$) so as to eliminate the secondary market ($q^*_{or} = 0$) (Region I_a). For $\delta_r < \widetilde{\delta_r}'$, there is no secondary market ($q^*_{or} = 0$) even at zero relicensing fee (Region I_b).*

Observation 2 allows us to distinguish between the case where the OEM decides to actively eliminate the secondary market from the case where the secondary market is not viable due to exogenous conditions. More specifically, for $\delta_r < \widetilde{\delta_r}'$, consumers' willingness-to-pay for a refurbished product is so low that maintaining a secondary market is not profitable for the third party regardless of the relicensing policy, that is, $q^*_{or} = 0$ even if $h^* = 0$. However, for $\widetilde{\delta_r}' < \delta_r < \widetilde{\delta_r}$, the secondary market would have been viable, but it is precisely the imposition of the relicensing fee that prohibits its existence. In this region, the OEM decides to eliminate the secondary market because the benefits stemming from the resale value effect and the relicensing revenues do not outweigh the losses from the cannibalization effect.

Observation 3: *When durability is low, no first-period customer continues using his product in the second period (Regions I and III), while when durability is high (region IV), all first-period customers do.*

In regions I and III, durability is low enough that the OEM cannot appropriate a sufficiently high value from customers who continue using their products in the second period, so she prefers instead to sell new products to all of them. Furthermore, in this range, the resale value of used products is zero. For sufficiently high δ_r (region III), the third party enters the secondary market. In contrast, when durability is high (region IV), it is optimal for the OEM to price such that all first-period customers continue using their products in the second-period, thus eliminating the secondary market. This happens not only because the OEM can appropriate the high value that consumers derive from a highly durable product in this manner, but also because the added value of refurbishing is low in this range.

Before moving to our analytical results, it is worth discussing how the above regions change with respect to c, c_r, and α. As c_r increases relative to c, refurbishing becomes more expensive, and region I where no secondary market exists grows at the expense of region III. In contrast, as c increases relative to c_r, region I shrinks: Focusing on new product sales becomes less profitable, and therefore, the range of parameters for which the OEM allows the secondary market to exist increases. In addition, region III shrinks (at the boundary with Region II) because for first-period customers, using their products for two periods rather than returning them and buying a new one again becomes more attractive as c increases. Region IV expands in c and c_r because the higher production cost drives the new product price up and encourages first-period customers to continue using their products, and the higher refurbishing cost hurts the entrant. Lastly, as α increases, the OEM's second-period new product becomes more attractive. Therefore, Region I where the third-party is unable to enter the secondary market expands; Region III, where all first-period customers replace their used product with a new one, expands at the expense of Region II; and Region IV where no first-period customer replaces his used product shrinks.

4.2. Structural Results and Comparative Statics

In this section, we prove properties of the equilibrium OEM relicensing policy and analyze the market dynamics with respect to key parameters. The analysis is focused on the most interesting case where all the market segments appear in equilibrium and the resale value is positive (region II_b). Where appropriate, we also discuss how the policy changes for parameter values outside this region. We begin with Proposition 1 and Lemma 1, which characterize the equilibrium strategy and provide comparative statics analysis when refurbishing is undertaken by a single third party. We then study the effect of competition in the secondary market: Proposition 2 examines the implications of an increasing number of third-party entrants who compete with each other in the secondary market, while Proposition 3 examines the effect of the OEM participating in the secondary market by refurbishing her own products. All proofs are provided in Appendix A.

PROPOSITION 1. *In region II_b where all market segments exist and the resale value is positive, the optimal relicensing fee h^* increases in δ_r and α, but decreases in δ, c and c_r.*

Based on this proposition, we can make a series of interesting observations concerning the drivers of the equilibrium where all segments exist.

The effect of durability vs. the added value of refurbishing.

Proposition 1 allows us to disentangle the effect of inherent product durability from the effect of the remanufacturing operation. One might expect δ and δ_r to have the same impact on h^*, since as they increase, they both make the second-period new product less competitive. Interestingly, Proposition 1 shows that they have opposite effects on the OEM's relicensing fee. A higher durability, δ, expands the market segment that chooses to continue using the product, and shrinks the segment of consumers who decide to sell their used products and buy a new one in the second-period. As a result, it becomes more expensive for the third party to obtain the used products. In order for the secondary market to remain viable, the OEM has to lower the relicensing fee. In contrast, a higher δ_r generates a higher willingness-to-pay for a refurbished product that the entrant exploits, which increases the threat of cannibalization. Consequently, as δ_r increases, the

OEM increases the relicensing fee, both to exploit the additional value that consumers place on the refurbished product and to keep cannibalization in check.

The effect of technology improvement, production cost and refurbishing cost.

While both a higher α and a higher c_r make the new product sold in the second period more competitive against the refurbished product, they have the opposite effect on h^*. As α increases, the utility that the first-period consumers obtain from selling their used units to the third party and buying a new one in the second period increases, so the third party can procure used products more cheaply. The OEM exploits this by increasing its relicensing fee. In contrast, a higher refurbishing cost c_r limits the ability of the third party to maintain a secondary market. As a result, the OEM attempts to strengthen the secondary market by lowering the relicensing fee. This is in line with Observation 1, where we saw that the OEM benefits from having a secondary market only when the entrant is competitive enough.

When the production cost c increases, h^* decreases. A higher production cost drives up the prices for new products, and reduces the number of consumers who are willing to replace their used product with a new one in the second period. As a result, the entrant faces higher procurement costs, which induces the OEM to reduce its relicensing fee so the secondary market will not shrink too much. At the same time, the OEM's new products becomes less competitive. The OEM can increase the relicensing fee to counter this effect. In region II_b, the first effect dominates and the relicensing fee decreases in c. In region II_a, where the supply of used units does not impose a constraint on the refurbished units such that $s^* = 0$, the first effect does not exist, and the OEM's relicensing fee increases in c. (Proposition 1 holds in region II_a for all other parameters.)

Lemma 1. *In region II_b where all market segments exist and the resale value is positive, the size of the secondary market $q^*_{or} = \frac{\alpha^2-(\delta+c+c_r)\alpha+\delta_r c}{4(\alpha^2+(\delta_r-\delta)\alpha-\delta_r{}^2)}$ increases in δ_r and decreases in δ, c and c_r. Lastly, it is either monotone increasing or unimodal (first decreasing, then increasing) in α for $\alpha \geq 1$.*

As δ_r increases or c_r decreases, refurbishing becomes more attractive to the third party; the OEM benefits from this by increasing h^*, but the net effect is that the size of the secondary market increases. On the other hand, as durability δ increases, the secondary market becomes less viable and its size decreases even as the OEM decreases h^*. The effect of the production cost c is driven by the constraint that the supply of used units imposes on the quantity of refurbished units. A higher c increases the procurement cost of the third party as it decreases the sale of new units in the first period. Consequently, despite the reduced competition in the second period, the size of the secondary market shrinks. The effect of α is driven by two opposing forces. On the one hand, as α increases, the procurement cost of the entrant decreases, which has a positive effect on the size of the secondary market. On the other hand, a higher α makes the second-period new product more competitive at the expense of the refurbished product. For low values of α, the latter effect may dominate the former such that the size of the secondary market decreases in α; otherwise, a higher α benefits the secondary market.

The Role of Competition.

Our analysis so far reveals a counterintuitive finding about the role of competition from a third-party entrant who collects, refurbishes, and sells products originally manufactured by the OEM. To further explore the impact of competition on the OEM's strategy, we take a two-pronged approach: i) We analyze the effect of the competitive intensity in the secondary market on the OEM's profit, and ii) We allow the OEM to interfere with the secondary market directly by refurbishing herself.

Competitive Intensity of the Secondary Market. The significant profit opportunity in the secondary market has given rise to a number of firms being founded with the sole purpose of buying and refurbishing used IT equipment (CBRonline.com 2005). According to the United Network Equipment Dealer Association (uneda.com), there are over 300 certified refurbishers today and many more who are not yet certified. To capture this phenomenon, we increase the competitive intensity within the secondary market by allowing N symmetric third-party entrants to compete in acquiring, refurbishing and reselling the used units. Each entrant determines the quantity q_r^j that he will place on the market. The price at which the refurbished products are sold p_r and the resale value s are determined by the total quantity $\sum_{i=1}^{N} q_r^i = Nq_r^{i*}$; this model is similar to Debo et al. (2005). The OEM determines the new product prices p_1 and p_2, and the relicensing fee h.

Proposition 2. *When all market segments exist in equilibrium, the OEM's profit is concave increasing in the number of third-party entrants N. In addition, $\frac{\partial^2 \Pi}{\partial N \partial c_r} < 0$, so as N increases the OEM has a higher incentive to invest in remanufacturability; that is, to decrease c_r.*

One may expect that as the number of entrants increases, the OEM profit suffers. Interestingly, however, the OEM's profit is concave increasing in the number of third-party entrants. The reason is as follows. Consistent with standard economic theory, as the number of entrants increases, internal competition drives the prices of the refurbished units down and the secondary market attracts more consumers (the overall quantity of refurbished units increases). As a result of this increased demand for the refurbished product, the resale value increases (when it is positive) in the number of entrants, and therefore, more first-period consumers are willing to resell their used product and purchase a new one. The OEM benefits not only from the higher resale value effect and the additional relicensing revenues from the growing secondary market, but also from the fact that first-period consumers are returning to the market to buy her new product.

The second part of Proposition 2 highlights an interesting contrast with the results in Debo et al. (2005), who find that an increase in the competitive intensity of the secondary market reduces both the OEM's incentive to invest in remanufacturability and her profit. This difference can be explained through the strategic as well as the economic role of the relicensing fee: The OEM not only has a more powerful mechanism of controlling the demand for refurbished products, she also derives revenues from the relicensing fee.

The OEM Participates in the Secondary Market. At first sight, our conclusion that the OEM welcomes competition in the secondary market seems counter to the previous results in the remanufacturing literature. For example, Ferrer and Swaminathan (2006) show a higher remanufacturing cost savings means higher participation by the OEM in the secondary market. Ferguson and Toktay (2006) find that as the third party becomes more competitive (c_r becomes lower) and the cannibalization threat increases, the OEM should increase her efforts to deter the secondary market. The difference in these findings is driven by how the OEM interferes with the secondary market. Remanufacturing is a direct approach, while imposing a relicensing fee is an indirect approach. In practice, some OEMs adopt a strategy of not participating in the secondary market, while others enter the refurbishing business themselves. To investigate the impact of the latter approach, we extend our baseline model to allow refurbishing by the OEM.

To analyze this case, we make the following assumptions to maintain tractability while gaining insight into the first-order effects: Consumers have the same willingness-to-pay for the product refurbished by the OEM and the third party. As a result, the price for a refurbished product is determined by the total quantity placed in the market by the two firms. In addition, we assume that the refurbishing cost is the same for the OEM and the third party. First, the OEM determines p_1, and then p_2 and h. Lastly, both the OEM and the third party decide on the quantity of refurbished units that they want to collect and refurbish. Let q_r^{OEM} and q_r^e be the quantities refurbished by the OEM and the third party, respectively.

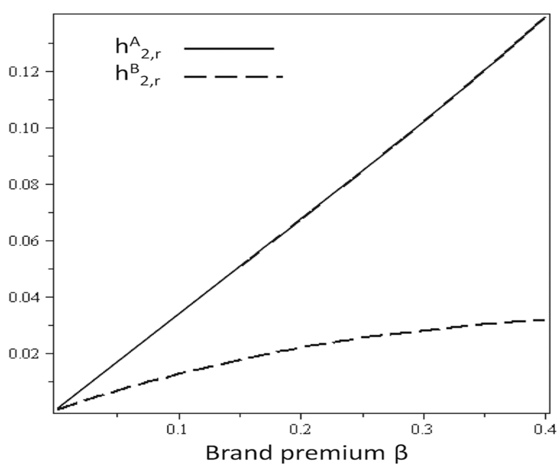
Proposition 3. *In equilibrium, when the OEM participates in the secondary market, the third party abstains* ($q_r^{e*} = 0$).

When the OEM is active on the secondary market ($q_r^{OEM*} > 0$), she fully exploits it for herself by setting the effective margin for the refurbished product so low that it is not profitable for the third party to participate ($q_r^{e*} = 0$). Intuitively, the relicensing fee allows the OEM to enjoy higher margins per unit of the refurbished product compared to the third party, making refurbishing profitable even when it is not so from the third party's perspective. Thus, the OEM can price out the third party through the strategic use of the relicensing fee, setting both the overall market size and the effective price $h + p_r$ per unit at the desirable level. Recall that the third party is only useful to the OEM because of the resale value effect and the relicensing revenues. These levers are also available to an OEM who remanufactures. In addition, if it is profitable for the third party to participate in the secondary market, then it is also profitable for the OEM to do so, and in fact, to completely take over the secondary market. If the OEM has a brand name or refurbishing cost advantage, this result is only strengthened. Nevertheless, in practice, there are OEMs who make a strategic choice not to enter the secondary market for reasons such as brand equity. While modeling this choice is beyond the scope of our paper, our analysis shows how the OEM can use the relicensing fee to shape the secondary market without participating in it directly.

5. Analysis: Differentiated Duopoly in the Primary Market

Thus far, we have assumed a monopolist setting in the primary market with the competition being restricted to the secondary market. In practice, the IT primary market is characterized by competition. Industry experts stress performance, efficiency, flexibility, longevity, reliability, and maintenance as factors of primary importance in the primary market (ServerWatch 2008, SearchServerVirtualization 2008). These are dimensions of vertical differentiation: For the same price, higher reliability, efficiency etc. are preferred to lower reliability, efficiency, etc. To capture this characteristic of the IT market, we develop a vertically differentiated duopoly model where consumers place a higher value on firm A's product over firm B's product. We address two critical questions: What are the pricing and relicensing strategies of each OEM and how do they differ? What is the impact of the quality (performance, reliability, etc.) differential on those strategies?

We capture the difference in the perceived quality between firms as follows: A consumer who derives utility θ from a new product by firm A derives utility $(1-\beta)\theta$ from a new product by firm B. We assume that $\beta > 0$ so that firm B represents the low-end firm. The relative difference in consumers' valuations, β, is called the "brand differential" or the "brand premium" of the high-end OEM. We also assume an equal rate of perceived utility depreciation for both firms. That is, a consumer derives utility $\delta_r\theta$ from firm A's refurbished product, while he derives utility $(1-\beta)\delta_r\theta$ from firm B's. This assumption allows us to maintain the same relative brand differential between the OEMs on the secondary market. We assume that $\delta_r < (1-\beta)$ so that a given consumer values the low-end firm's new product strictly more than the high-end firm's refurbished product. This is a reasonable assumption based on the current state of the IT industry where we do not observe significant variation among the prices of new products across different OEMs, but we observe a significant drop for refurbished products, which are typically sold at 40%-70% of the price for the corresponding new product. Finally, to maintain tractability, we focus on the region where $\delta << \delta_r$ so that the refurbishing process adds significant value to a used product. As a result, and based on the discussion of our baseline model, we assume that all consumers replace their products in the second period. Not making this assumption would result in having ten different consumer strategies over the two-period horizon, a model that is intractable. Since our goal is to study the effect of the brand premium on both the high-end OEM's and the low-end OEM's secondary markets, we limit our attention to those parameter values where the third-party entrant refurbishes both products. Observations 4 and 5 below summarize the effect of the brand premium on the relicensing fee strategy and the nature of the secondary market in this range, and Figure 2 demonstrates these observations.



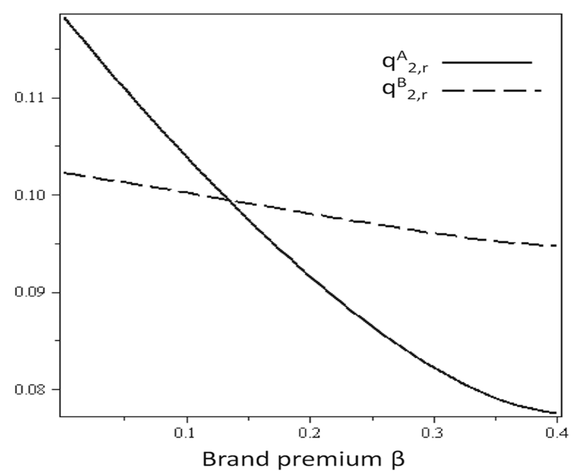


Figure 2 **Relicensing fees (left) and equilibrium refurbished product quantities in the second period (right) as a function of β for δ_r=0.7, c=0.2, and c_r=0.05.**

Observation 4: *The high-end OEM always charges a higher relicensing fee than the low-end OEM and the difference between the relicensing fees increases in the brand premium.*

This is because the high-end OEM's relative brand premium exists in the secondary market as well, which she capitalizes on by charging a higher relicensing fee. Note that despite the higher relicensing fee h_A^*, the high-end OEM maintains an active secondary market. Thus, a high relicensing fee need not be indicative of an attempt to shut down the secondary market, but may rather reflect the brand premium a particular OEM commands.

Observation 5: *There is a threshold value for the brand premium, $\tilde{\beta}$, above which the low-end OEM's product makes up a larger share of the secondary market than the high-end OEM's product.*

Observation 5 suggests that although a positive brand premium always translates to a larger market share in the primary market (under symmetric production costs), the same is not true for the corresponding secondary markets. Interestingly, it is precisely when the brand differential is large that the low-end OEM's product dominates the secondary market. This counter-intuitive result can be explained through the effect of the relicensing fees. The demand for each type of refurbished product increases in the consumer willingness-to-pay for it and decreases in the corresponding relicensing fee. For low β values, the former effect dominates the latter, and the high-end OEM's product has a larger share. For high β values, however, the opposite is true: the increasing difference between h_A^* and h_B^* shifts the demand away from the high-end OEM's refurbished product to the low-end OEM's refurbished product. This result could explain the strategy of some high-end OEMs who choose not to have large secondary markets for their refurbished product despite the brand premium they command.

6. Conclusions

Secondary markets in the IT industry have grown steadily, forcing OEMs to form strategies to respond to them. For products such as servers and storage devices, OEMs have a powerful mechanism at their disposal: instituting a software relicensing fee to any second-hand users of the OEMs' products. A high relicensing fee can virtually shut down the secondary market, while a low relicensing fee can allow it to thrive. The optimal strategy is not obvious: An active secondary market not only generates relicensing revenues for the OEM but also has an indirect positive benefit of increasing the OEM's new product's resale value, which in turn, increases the price that can be charged for the new product (resale value effect). At the same time, an active secondary market has a direct detrimental effect as the refurbished product competes with the OEM's new product (cannibalization effect). In practice, we observe comparable OEMs with surprisingly different relicensing fee strategies. The existing literature on secondary markets does not provide guidance concerning this widespread mechanism. In this paper we fill this gap by contributing to the theory of secondary markets and by providing managerial guidelines on the use of relicensing fees.

Our research makes several theoretical contributions to the literature on how OEMs should balance their primary and secondary markets. First, we explicitly model the role of the relicensing fee. Though widespread, the relicensing fee mechanism has not been studied in the literature to date. Our paper is the first to examine both the economic (i.e., direct revenues) and the strategic (i.e., interference mechanism) implications of this mechanism. Second, unlike prior research that assumes that used units are traded among consumers in a perfectly competitive market, we model the incentive of independent third-party entrants to purchase, refurbish, and resell those used units. By doing so, we account for the operational realities of maintaining a secondary market, that is, the refurbishing process. In practice, reselling an IT product worth several thousand dollars requires a number of procedures (e.g., replacing hardware components, testing performance, etc.) that are not costless. As our analysis reveals, the effect of such procedures, proxied by the value added by the refurbishing process and the magnitude of the refurbishing cost, are key determinants of the OEM's strategy vis-à-vis the secondary market. In addition, by explicitly modeling the independent third-party entrants, we are able to examine how an increase in the competitive intensity in the secondary market (i.e., higher number of entrants) affects the OEM's strategy. Third, current theoretical frameworks that consider a monopolist OEM have limited power in explaining the adoption of different secondary market strategies by competing OEMs. In our duopoly model, we capture the equilibrium relicensing fee strategies of competing OEMs and compare how they evolve as the brand premium between them increases. To our knowledge, our paper is the first to study differentiated new and refurbished products competing in both the primary and secondary markets.

In parallel, we complement the rapidly growing literature on remanufacturing by linking the consumers' willingness-to-pay for a new product to the potential resale value of the product at the end of use. By doing so, we show that a market for refurbished products can benefit the OEM even if it is operated by independent third parties. Finally, our comprehensive model allows us to disentangle the effect of inherent product durability from the effect of the remanufacturing process. Prior work on remanufacturing assumes that after one period of use, the product has zero utility for the consumer unless it is refurbished, in which case it offers a fraction of the utility offered by a new product. In contrast, the literature on durable goods assumes that a product can be used in subsequent periods as is, offering the consumer a fraction of its original utility. Our model is the first to integrate these two effects, namely, the inherent durability of the product and the value added by the refurbishing process. We show that although they both imply that the used or refurbished product is a closer substitute to the new product, their effect on the OEM's relicensing fee strategy is diametrically opposite.

Our results help IT OEMs to identify critical tradeoffs involving the relicensing fee along the dimensions of consumer preferences, refurbishing cost, and competitive dynamics. We find that the OEM should allow for a secondary market when consumers' willingness-to-pay for a refurbished product is sufficiently high relative to the inherent product durability. At first sight, this result is surprising since the secondary market is operated by third-party entrants who become more competitive as consumers place more value on the refurbished product. This finding is explained by the fact that it is precisely when the refurbished product is valuable that the OEM can profitably use the relicensing fee to exploit the resale value effect and the relicensing fee revenue to her advantage. This is especially important for an OEM with high production costs: The right combination of price and relicensing fee allows the OEM to mitigate the low margin of her new product by producing fewer units but charging a price premium for them thanks to the resale value effect. Finally, the strategic and economic value of an active secondary market for the OEM is amplified as it faces competition from a larger number of third-party entrants. In our experience, OEMs are very concerned with cannibalization. What these results say is that when using the relicensing fee mechanism only to interfere with the secondary market, it is precisely in cases where cannibalization is a strong threat that the OEMs should embrace the secondary market. This requires a strategic shift in the OEM's approach relative to the case where she refurbishes her own products.

Finally, our differentiated duopoly model offers insights regarding the different relicensing fee strategies observed in practice. As we would expect, the high-end OEM charges a higher relicensing fee since her brand premium is maintained in the secondary market. In fact, the high-end OEM should monotonically increase her relicensing fee as her brand premium is strengthened. Interestingly, however, although a higher brand premium translates into a larger market share in the primary market, the same is not true for the secondary market. When her brand premium is large enough, the high-end OEM finds the primary market more attractive, and chooses her relicensing fee so as to encourage the low-end OEM to focus on the secondary market. This result could explain the strategy of some high-end OEMs who choose not to have large secondary markets for their refurbished units despite the brand premium that they command.

To conclude, our paper highlights the strategic importance of supporting an active secondary market under a wide range of circumstances, particularly when consumers form expectations about the future resale value of their products and the refurbishing process adds value at relatively low cost. These conditions are valid in the IT industry today: There exist a large number of industry analyst firms who specialize in forecasting the resale value of IT equipment and who offer comprehensive cost/benefit analysis over the life-cycle of the IT equipment while the modularity of IT solutions makes refurbishment a cost-effective proposition for many products.

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Appendices

Appendix A: Proofs

Proof of Proposition 1. To obtain the equilibrium in Region II_b, we can write the OEM's second-stage optimization problem as $Max_{p_2,h\in S}\Pi_2(p_2,h|p_1)$, where $\Pi_2(p_2,h) = (p_2 - c)(q_{nn} + q_{on}) + hq_{or}$ and S_1 is the region where $q^*_{nn} > 0$, $q^*_{nu} > 0$, $q^*_{on} > 0$, $q^*_{or} = q^*_{nn}$ and $s^* > 0$ hold at the entrant's best response $p^*_r(p_2,h|p_1)$ and $s^*(p_2,h|p_1)$. This gives $p^*_2 = \frac{\alpha p_1+c+\delta c}{2(1+\delta)}$ and $h^* = \frac{-\delta^2+(-1+\alpha-c_r)\delta+(1-p1)\alpha-c_r+\delta_r p_1}{2(1+\delta_-}$. In the first period, the OEM's problem can be written as $Max_{p_1}\ \Pi_1(p_1) + \Pi^*_2(p_1)$, where $\Pi_1(p_1) = (p_1 - c)(q_{nn} + q_{nu})$. This gives $p^*_1 = \frac{(2\alpha-4-2c)\delta+(c+2)\alpha-2-2c-2\delta^2}{3\alpha-4\delta-4}$, and thus, $h^* = \frac{4\delta^3+(8-5\alpha+4c_r-2\delta_r)\delta^2+\left(\alpha^2+(-3c_r+2\delta_r+2c-7)\alpha+(-4-2c)\delta_r+4+8c_r\right)\delta+(1-c)\alpha^2+((c+2)\delta_r+2c-2-3c_r)\alpha-2(1+c)\delta_r+4c_r}{2(3\alpha-4\delta-4)(1+\delta)}$.

Then $\frac{d(h^*)}{d\delta_r} = \frac{\alpha+1/2\,c\alpha+\delta\,\alpha-c-1-2\delta-c\delta-\delta^2}{(3\alpha-4\delta-4)(1+\delta)} > 0$ because the denominator is always negative and the numerator is also negative for $\alpha < 1+\delta$. $\frac{d(h^*)}{dc} = -\frac{(1/2\,\alpha-1-\delta)(\alpha-\delta_r)}{(3\alpha-4\delta-4)(1+\delta)} < 0$ and $\frac{d(h^*)}{dc_r} = -\frac{1}{2} < 0$.

$\frac{d(h^*)}{d\delta} = \frac{3/2\,\alpha^3 c+1/2\left(-11\,\delta^2+(-8\,c-22)\delta-11+(-3\,\delta_r-8)c\right)\alpha^2+1/2\,(8+8\,\delta)\left(3\,\delta^2+(1/4\,\delta_r+6+c)\delta+(\delta_r+1)c+1/4\,\delta_r+3\right)\alpha-4\,(1+\delta)^2\left(2\,\delta^2+4\,\delta+2+\delta_r\,c\right)}{(3\,\alpha-4-4\,\delta)^2(1+\delta)^2}$.

Let Φ_1 denote the numerator of this expression. $\frac{d\Phi_1}{dc} = 1/2\,(-8\,\delta\,\alpha+3\,\alpha^2+16\,\delta+8\,\delta^2+8-8\,\alpha)\,(\alpha-\delta_r) > 0$ so Φ_1 increases in c. We will show that $\Phi_1(c=1)$ is negative so Φ_1 is negative on [0,1]. Let $\Phi_2 \doteq \Phi_1(c=1) = -8\,\delta^4 + (12\,\alpha-32)\,\delta^3 + (-11/2\,\alpha^2+41\,\alpha-52)\,\delta^2 + (-15\,\alpha^2+50\,\alpha-40)\,\delta + 3/2\,\alpha^3 - 11\,\alpha^2 - 12 + 21\,\alpha$. Then $\frac{d\Phi_2}{d\alpha} = 9/2\,\alpha^2 - 11\,\alpha\,\delta^2 - 30\,\alpha\,\delta - 19\,\alpha - 3\,\alpha\,\delta_r + 12\,\delta^3 + 40\,\delta^2 + \delta^2\delta_r + 6\,\delta\,\delta_r + 44\,\delta + 5\delta_r + 16$, which is positive on $[1, 1+\delta)$ because it decreases in α ($\frac{d^2\Phi_2}{d\alpha^2} = 9\alpha - 11\delta^2 - 30\delta - 19 - 3\,\delta_r < 0$) and $\frac{d\Phi_2}{d\alpha}\Big|_{\alpha=1+\delta} = \frac{1}{2}(1+\delta)(2\delta^2+5\delta+2\delta\delta_r+4\delta_r+3) > 0$. So Φ_2 increases in α and reaches its maximum value on $[1, 1+\delta]$ at $1+\delta$, which is $\Phi_2(\alpha=1+\delta) = -1/2\,(\delta+1)^2\,(3\,\delta^2+3\,\delta-2\delta\delta_r+\delta_r) < 0$. Thus, Φ_1 is negative on $[1, 1+\delta]$, and $\frac{dh^*}{d\delta} < 0$. $\frac{dh^*}{d\alpha} = \frac{\left(4\,\delta^2+3/2\,(-2/3\,\delta_r-8/3\,\alpha+16/3)\delta-4\,\alpha+3/2\,\alpha^2+4-\delta_r\right)(1-c+\delta)}{(-4+3\,\alpha-4\,\delta)^2(1+\delta)}$. Let $\Phi_3 \doteq (4\,\delta^2 + 3/2\,(-2/3\,\delta_r - 8/3\,\alpha + 16/3)\,\delta - 4\,\alpha + 3/2\,\alpha^2 + 4 - \delta_r)$. $\frac{d\Phi_3}{d\alpha} = 3\alpha - 4 - 4\delta < 0$ because $\alpha < 1+\delta$ by assumption. Also $\frac{d(\Phi_3)}{d\alpha}\Big|_{\alpha=1+\delta} = \frac{1}{2}(1+\delta)(3\delta+3-2\delta_r) > 0$, so $\Phi_3 > 0$ for $\alpha \in [1, 1+\delta]$ and thus, $\frac{dh^*}{d\alpha} > 0$ in this range.

Proof of Lemma 1. In region II_b, $q^*_{or} = \frac{\alpha^2-(\delta+c+c_r)\alpha+\delta_r c}{4(\alpha^2+(\delta_r-\delta)\alpha-\delta_r{}^2)}$. Thus, $\frac{\partial q^*_{or}}{\partial c} = \frac{\alpha-\delta_r}{4(\alpha^2+(\delta_r-\delta)\alpha-\delta_r{}^2)} >$

0, $\frac{\partial q_{or}^*}{\partial c_r} = -\frac{\alpha}{4\,\alpha^2+(-4\,\delta+4\,\delta_r)\alpha-4\,\delta_r{}^2} < 0$, $\frac{\partial q_{or}^*}{\partial \delta} = -\frac{\left(\alpha c_r+c\alpha+\alpha\delta_r-\delta_r{}^2-\delta_r c\right)\alpha}{4\left(\alpha^2-\delta\,\alpha+\alpha\,\delta_r-\delta_r{}^2\right)^2} < 0$, and $\frac{\partial q_{or}^*}{\partial \delta_r} = \frac{-\alpha^3+2\delta_r\alpha^2+\alpha^2 c_r+2c\alpha^2+\delta\alpha^2-2\,\alpha\delta_r(c_r+\delta+c)-c\delta\alpha+c\delta_r{}^2}{4\left(\alpha^2-\delta\,\alpha+\alpha\,\delta_r-\;\delta_r{}^2\right)^2}$. Let $\Phi_4 = -\alpha^3 + 2\delta_r\alpha^2 + \alpha^2 c_r + 2c\alpha^2 + \delta\alpha^2 - 2\,\alpha\delta_r c_r - 2\delta_r\delta\alpha - 2\delta_r c\alpha - c\delta\alpha + c\delta_r{}^2$. To show that $\frac{\partial q_{or}^*}{\partial \delta_r} > 0$ it is sufficient to show that $\Phi_4 > 0$. $\frac{d\Phi_4}{d\delta_r} = 2(\alpha^2 - (c_r + \delta + c)\alpha + \delta_r c) > 0$ (because the expression in brackets is the same as the numerator of q_{or}^*, which is positive by assumption) and $\frac{d^2\Phi_4}{d\delta_r^2} = 2c > 0$, so Φ_4 is convex increasing. Let $\tilde{\delta}_r$ solve $q_{or}^* = 0$. $\tilde{\delta}_r$ is also the minimizer of Φ_4. Thus, Φ_4 is increasing where $q_{or}^* > 0$ and can have at most one root, call it δ_{r0}, in this range. Then Φ_4 will be negative on $(\tilde{\delta}_r, \delta_{r0})$, which implies q_{or}^* decreases in this range. We know that q_{or}^* is locally increasing at $\tilde{\delta}_r$, so by contradiction, Φ_4 has no root (and is positive) where $q_{or}^* > 0$. Consequently, q_{or}^* increases monotonically in δ_r. Finally, $\frac{\partial q_{or}^*}{\partial \alpha} = \frac{(\delta_r+c+c_r)\alpha^2-2\delta_r(\delta_r+c)\alpha+(\delta_r(\delta+c_r)+\delta c)\delta_r}{4(\alpha^2+(\delta_r-\delta)\alpha-\delta_r{}^2)^2}$, thus the sign of $\frac{\partial q_{or}^*}{\partial \alpha}$ is driven by the sign of the numerator. The numerator is quadratic with a positive leading coefficient. Its minimizer is $\frac{\delta_r(\delta_r+c)}{\delta_r+c+c_r} < 1$, so in the range $\alpha \geq 1$, the numerator is either first negative and then positive, or always positive.

Proof of Proposition 2. Let $Q_r^{-i} = \sum_{j=1, j\neq i}^{N} q_r^j$. Then we can rewrite the i^{th} third party's problem as:

$$Max_{q_r^i}\Pi_e = (p_r - s - c_r)q_r^i$$
$$\text{s.t. } q_r^i + Q_r^{-i} \leq q_{nn}$$
$$q_r^i \geq 0.$$

Since we assume N symmetric entrants, $Q_r^{-i*} = (N-1)q_r^{i*}$. The equilibrium resale value s^* is determined by the market clearing condition $Nq_r^{i*} = q_{nn}(s^*)$. To obtain the equilibrium in Region II_b, we can write the OEM's second-stage optimization problem as $Max_{p_2, h\in S}\Pi_2(p_2, h|p_1)$, where $\Pi_2(p_2, h) = (p_2 - c)(q_{nn} + q_{on}) + h(Nq_r^i)$ and S_1 is the region where $q_{nn}^* > 0$, $q_{nu}^* > 0$, $q_{on}^* > 0$, $q_{or}^* = q_{nn}^*$ and $s^* > 0$ hold at the entrant's best response $p_r^*(p_2, h|p_1)$ and $s^*(p_2, h|p_1)$. In the first period, the OEM's problem is $Max_{p_1}\ \Pi_1(p_1) + \Pi_2^*(p_1)$, where $\Pi_1(p_1) = (p_1 - c)(q_{nn} + q_{nu})$. The above system can be solved by backwards induction in a way similar to the one described for the case where $N = 1$. In the equilibrium where all segments are positive, once we substitute (p_1^*, p_2^*, h^*), the first derivative of the profit function with respect to the number of entrants N is $\frac{\partial \Pi}{\partial N} = \frac{\left(-\alpha^2+(c+c_r+\delta)\alpha-c\delta_r\right)^2(\alpha-\delta_r)\delta_r}{4\alpha\left((\alpha^2+(\delta_r-\delta)-\delta_r{}^2)N+\delta_r\alpha-\delta_r{}^2\right)^2} > 0$, so the OEM's profit increases in N. Also $\frac{\partial^2 \Pi}{\partial N^2} = -\frac{\left(-\alpha^2+(c+c_r+\delta)\alpha-c\delta_r\right)^2(\alpha-\delta_r)\delta_r\left(\alpha(\alpha-\delta)+\delta_r(\alpha-\delta_r)\right)}{2\alpha\left((\alpha^2+(\delta_r-\delta)-\delta_r{}^2)N+\delta_r\alpha-\delta_r{}^2\right)^3}$. The bracketed term in the denominator $(\alpha^2+(\delta_r-\delta)-\delta_r{}^2)N+\delta_r\alpha-\delta_r{}^2$ is always positive because it increases in N, and for $N=1$ is equal to $\alpha(\alpha-\delta)+2\,\delta_r\,(\alpha-\,\delta_r)>0$. Therefore, $\frac{\partial^2\Pi}{\partial N^2}<0$. Finally, we will show that $\frac{\partial^2\Pi}{\partial N \partial c_r}<0$. We have that $\frac{\partial^2\Pi}{\partial N\partial c_r} = -\frac{\left(\alpha^2-(c+r+\delta)\alpha+c\delta_r\right)(\alpha-\delta_r)\delta_r}{2\left((\alpha^2+(\delta_r-\delta)-\delta_r{}^2)N+\delta_r\alpha-\delta_r{}^2\right)^2}$. The denominator is positive and so is the term $\alpha-\delta_r$. To establish the sign of the remaining term, note that it appears in the numerator of $q^*_{nn} = \frac{1}{2}\frac{(\alpha^2-(\delta+c+c_r)\alpha+\delta_r\,c)N}{\left((\alpha^2+(\delta_r-\delta)-\delta_r{}^2)N+\delta_r\alpha-\delta_r{}^2\right)}$. The denominator of q_{nn} is positive by the previous argument. Since we are in the parameter space where $q^*_{nn}>0$, its numerator has to be positive, and we conclude that $\frac{\partial^2\Pi}{\partial N\partial c_r}<0$.

Proof of Proposition 3. The second-stage game where the OEM and the third party determine the quantities q_r^{OEM} and q_r^e can be formulated as:

$$Max_{q_r^e}\Pi_e(q_r^e) = (p_r-s-c_r)q_r^e$$

$$Max_{q_r^{OEM}}\Pi_2(q_r^{OEM}) = (p_2-c)(q_{nn}+q_{on})+h(q_r^{OEM}+q_r^e)+(p_r-s-c_r)q_r^{OEM} \text{ s.t. } q_r^e+q_r^{OEM}\le q_{nn},$$

$$q_r^e\ge 0,\; q_r^{OEM}\ge 0.$$

Assume for the moment that there is sufficient availability of used products so that the constraint $q_r^e+q_r^{OEM}\le q_{nn}$ is always non-binding. That is, both the third party and the OEM could acquire and refurbish as many units as they wanted. This is the best-case scenario for the third-party, but the OEM nevertheless uses the relicensing fee to deter his entry: Solving the three-stage game by backwards induction, where first the OEM sets p_1, then she sets p_2, and h, and finally, in the third stage, the OEM and the third party simultaneously set q_r^{OEM} and q_r^e, we can derive the equilibrium resale value, s^*, and price for the refurbished product, p_r^*. In particular, $p_r^*-s^*-c_r=0$, which suggests that the OEM sets p_1^*, p_2^*, and h^*, so that the margin from refurbishing a unit of used product is zero for the third-party entrant (but not for the OEM, thanks to the relicensing fee). As a result, it is never profitable for the entrant to enter the secondary market and $q_r^{e*}=0$.

Appendix B: Competition in both the primary and secondary markets with brand differentiation.

The sequence of events is as follows. In the first period, the two OEMs compete in the market by simultaneously setting the quantities q_1^A and q_1^B. In the second period, the two OEMs again set the new product quantities q_2^A and q_2^B and at the same time determine the relicensing fees for their refurbished products, h^A and h^B. Lastly, the third-party entrant decides the quantities to refurbish for each brand, $q_{2,r}^A$ and $q_{2,r}^B$. We solve the problem by backward induction, starting with the entrant's objective function, and then moving to the OEMs' second- and first-period objective functions. Unfortunately, characterizing the equilibrium for a durable product in a duopoly setting is a non-trivial task. In particular, there are ten different consumer strategies as opposed to the four that we had in the baseline model. As explained in the text, in order to obtain a tractable model, we assume that all first-period consumers resell their used product and buy a new one. Essentially, we focus on the region where $\delta_r >> \delta$ so that the refurbishing process adds significant value to a used product. While we recognize the limitations of such an assumption, it may not be as restrictive as it appears since there is substantial value added from refurbishing for the majority of IT equipment. Mathematically, this assumption allows us to decouple the two periods, and divide the second-period consumer state space to only four segments.

The net utility that consumer θ derives is $U_2^A(\theta) = \theta - p_2^A$ from purchasing firm A's new product, $U_2^B(\theta) = (1-\beta)\theta - p_2^B$ from purchasing firm B's new product, $U_{2,r}^A(\theta) = \delta_r\theta - p_{2,r}^A - h^A$ from buying firm A's refurbished product, and $U_{2,r}^B(\theta) = (1-\beta)\delta_r\theta - p_{2,r}^B - h^B$ from buying firm B's refurbished product. Solving for the marginal consumers, we get

$$\theta_1 = \frac{p_2^A - p_2^B}{\beta}, \theta_2 = \frac{p_2^B - p_{2,r}^A - h^A}{1-\beta-\delta_r}, \theta_3 = \frac{p_{2,r}^A - p_{2,r}^B + h^A - h^B}{\beta\delta_r}, \theta_4 = \frac{p_{2,r}^B + h^B}{(1-\beta)\delta_r}$$

with respective demand for each product of $q_2^A = 1-\theta_1$, $q_2^B = \theta_1 - \theta_2$, $q_{2,r}^A = \theta_2 - \theta_3$, and $q_{2,r}^B = \theta_3 - \theta_4$.

The entrant's optimization problem is to decide on the quantities $q_{2,r}^A$ and $q_{2,r}^B$ to maximize:

$$Max_{q_{2,r}^A, q_{2,r}^B}\ \Pi_e(q_{2,r}^A, q_{2,r}^B) = (p_{2,r}^A - c_r)q_{2,r}^A + (p_{2,r}^B - c_r)q_{2,r}^B.$$

The second-period optimization problems for firms A and B are

$$Max_{q_2^A, h^A}\Pi_2^A(q_2^A, h^A | q_2^B, h^B) = (p_2^A - c)q_2^A + h^A q_{2,r}^{A*}$$
$$Max_{q_2^B, h^B}\Pi_2^B(q_2^B, h^B | q_2^A, h^A) = (p_2^B - c)q_2^B + h^B q_{2,r}^{B*}.$$

We verify that the conditions for a unique unconstrained Nash Equilibrium are met (convex strategy set, Hessian negative definite). Solving the first-order conditions simultaneously, we derive the Nash equilibrium of this game for given q_1^A and q_1^B : $q_2^{A*}(q_1^A, q_1^B)$, $h^{A*}(q_1^A, q_1^B)$, $q_2^{B*}(q_1^A, q_1^B)$, $h^{B*}(q_1^A, q_1^B)$.

Finally, the first-period profits are given by $\Pi_1^A(q_1^A|q_1^B) = (p_1^A - c)q_1^A$ and $\Pi_1^B(q_1^B|q_1^A) = (p_1^B - c)q_1^B$, while the overall profits over the two-period horizon are:

$$Max_{q_1^A, h^A} \Pi_A(q_1^A|q_1^B) = (p_{1A} - c)q_1^A + \Pi_{2A}^*(q_1^A|q_1^B)$$
$$Max_{q_1^B, h^B} \Pi_B(q_1^B|q_1^A) = (p_{1B} - c)q_1^B + \Pi_{2B}^*(q_1^B|q_1^A)$$

where the asterisks in the second-period profit functions denote that all second-period actions are in equilibrium. By solving the first-order conditions corresponding to these objective functions simultaneously, we derive the Nash equilibrium q_1^{A*} and q_1^{B*}. Although we are able to derive closed-form expressions for all decision variables, they are very long, so we do not report them, but we use them in the analysis leading to Observations 4 and 5.