Optimal quality design when a product is customized by a customer using third-party firm's items under the uncertainty of customer's preference

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Abstract. Customers often customize durable consumer products after purchase by adding accessories and peripheral items. Personalization of a smartphone or a passenger car is a good example of such customer customization. Manufacturers often earn profits through the sale of accessories and peripheral items used for customer customization; however, compatible products offered by third parties may undermine a manufacturer's profits. This paper investigates how manufacturers can determine the optimal quality level of their main durable consumer products to which accessories and consumable items can be attached when the quality level influences the purchase decisions of consumers whose preference for the product is uncertain and heterogeneous. In addition, we examine how this product quality decision is affected by the existence of low-priced compatible peripheral items made by a third-party firm. Finally, we provide the managerial implications for consumer product design derived from analytical models.

Keywords: Product design; Customer customization; Razor and razor blade model; Consumer heterogeneity

1. INTRODUCTION

Customization of a durable product is strategically important. Mass customization—the manufacturing technology that processes personalized goods with the efficiency of mass production—has gained increasing attention of practitioners (Paresh, 2012). Another type of product customization is one in which a consumer personalizes a manufacturer's product after purchase (referred to hereafter as *customer customization*). For example, smartphone users can install many applications and delete some unnecessary pre-installed applications after purchasing a phone. Similarly, automobile owners may personalize their car by installing various car accessories such as fog lamps, a roof carrier, and sheet covers and/or by changing pre-installed parts such as wheel covers, tires, and the mufflers. Customer customization of a product, which can be regarded as a value co-creation process, has been discussed in relation to business strategies (Prahalad and Ramaswamy, 2004; Wind and Rangaswamy, 2001), operations management (Xia and Rajagopalan, 2009), and marketing (Franke et al., 2009; Franke and Schreier, 2010). Murthi and Sarkar (2003) reported an intensive survey of product personalization.

A business model that is closely related to customer customization is the *razor and razor blade model*, in which the firm of a consumer product earns profit not from the sale of a main, durable product but from the sale of a consumable item required for use of the main durable product (Schmalensee, 2015). As its name implies, the model refers to the classic business model example in which a razor user must repeatedly purchase razor blades to use with the razor holder. In real-world business, the user of a durable product can choose their preferred consumable item from several options. For example, Gillette offers consumers different types of razor blades (e.g., three-blade, four-blade, and five-blade sets) that can be attached to a certain type of razor holder. In addition, a smartphone or tablet user who installs a microSD memory card to expand the device's storage space can choose from several capacities (e.g., 4, 8, 16, 32 GB). Thus, one challenge for a firm adopting the razor and razor blade model is the way the functionality and product features of a durable product (which we call a *main* or *base product*) are designed, which influences the extent to which a customer can customize his or her product using the variety of supplemental items, accessories, and after-sales packages (hereafter referred to as *accessories*). The potential for customer customization determines the

consumer's preference for the product, which eventually influences the profits of the firm.

However, one concern for the manufacturer that adopts the razor and razor blade model is low-priced compatible products offered by third party firms (Erzurumlu, 2013). For example, compatible ink cartridges are available from electronic appliance shops and over the internet. This implies that the profitability of brand-name printer companies, such as HP and Canon, could be undermined by the existence of low-priced, generic items from third parties. In fact, brand manufacturers attempt to discourage consumers from buying third-party generic products (e.g., a message may be attached to a main product warning that the warranty becomes invalid if unofficial consumable items are used). They may also sue a third-party firm for infringement of intellectual property rights (e.g., an article in Wall Street Journal (Online), March 8, 2010).

A brand manufacturer should determine the extent of functionality and features pre-installed to a base durable product by considering the potential sale of accessories and the competition with the generic products sold by third parties. In this paper, we use the term "quality" to denote the set of product features and functionality that durables possess. We assume that a higher quality level results in a higher utility level for the consumer. In other words, the heterogeneity setting in this paper is a type of vertical product differentiation.

Note that there is a trade-off in the design of base product quality. On one hand, if the base product is of very high quality, a customer's willingness to buy accessories would be dampened. For example, it is intuitively convincing that if many popular applications are pre-installed on a smartphone, the chance that the user of the device would pay for additional applications is reduced, which may reduce the firm's profitability. On the other hand, if product quality is relatively low, consumers may regard it as less attractive or very expensive to personalize the product, which results in low product profitability. For example, if the specifications of a computer are very poor, users of gaming software packages that require high-quality graphics and sound will not choose such a computer even if its price is reasonable. Therefore, a critical challenge for a consumer product manufacturer is to determine the optimal level of quality for a consumer product by balancing the potential for customers customization, which influences the sale of accessories in the future, with an attractiveness that consumers recognize, which affects the sale of the main durables and, consequently, the sale of accessories in the future.

The goal of this paper is to determine the optimal quality level of a durable consumer product when the manufacturer of the durable product adopts the razor and razor blade model, competes with a third-party firm that sells generic compatible products, and aims to balance the attractiveness of the product with the potential for customer customization. We also focus on customer preference for product quality being heterogeneous. In particular, using analytical and numerical approaches, we answer the following questions:

1. What is the optimal level of quality for a durable product when the sale of accessories is a key source of revenue for the manufacturer?
2. How is the optimal design influenced by managerial environment changes such as the profit margin of accessory sales, the cost of buying accessories, and the price of the durable?
3. How much does the optimal design change when the retail price is influenced by its quality level?

In this paper, we formulate a mathematical model and analytically derive the answers. Based on the model solutions, we then report several managerial implications. Our analysis concludes that in general the quality of the durable should be as low as possible when the brand equity is relatively high. However, we find that the optimal quality will be greater than the minimum level if the target market is low-end users.

The remainder of this paper is organized as follows. Section 2 briefly explains the model assumptions and formulates the mathematical models. Section 3 analyzes the model and proposes the answers to the aforementioned research questions. Section 4 discusses the managerial implications that are derived from the analytical results. Finally, Section 5 concludes the paper.

2. MODEL

This paper determines the optimal quality level of a base durable product when customers whose quality preference is greater than that of the base model are assumed to buy accessories to personalize the product and where sales of such the accessories generate profit. The details of our model settings are as follows.

2.1. Product quality

In our analysis, the quality level that a firm adopts follows a vertical differentiation setting: The higher the level of product quality, the greater the number of satisfied customers (Vandenbosch and Weinberg, 1995). For instance, the duration of warranty coverage for a consumer durable and the memory size of a computer can be considered such quality attributes. We assume that the size of customers is standardized one. Then, the difference in a customer's evaluation of quality is represented by his or her location on the interval [0,1], with a customer located at a higher position on the 0–1 interval having a higher preference for quality (Desai, 2001; Alptekinoğulu and Corbett, 2008; Mendelson and Parlakturk, 2008). This setting of customer preference has been commonly used in published articles relating to operations, including those by Yu (2012), Liu & Zhang (2013), Loginova and Wang (2013), Cheng (2014), and Nguyen et al. (2014). A firm's decision on

the optimal quality level x^* takes into account a trade-off: a durable of high quality may attract many customers, but the firm may lose sales of profitable accessories; whereas a durable with low quality may encourage customers to buy accessories, but, at the same time, the low quality may negatively affect the sale of the durable.

We let the lowest and highest quality levels that a firm predetermines for a targeted market be θ_L and θ_U, respectively ($0 < \theta_L < \theta_U < 1$). That is, the firm sets the quality level x by focusing on consumers whose quality preference is located between θ_L and θ_U. In other words, we assume that customers located below θ_L or above θ_U do not buy the firm's product.

2.2 Utility functions

As shown in Figure 1, our model assumes that when the quality level of the base product is x ($\in [\theta_L, \theta_U]$), a customer whose utility is less than or equal to x is assumed to buy only a base product (hereafter a *base user*), whereas a customer located above x will buy a base product and accessories that are used to customize the base model (hereafter a *customizer*). At the same time, it is assumed that a customer whose utility is non-positive, or one who is located outside of the target range $[\theta_L, \theta_U]$, will not buy any product. To describe this framework, the utility function of a base user with preference θ ($\theta \in [0,1]$) is defined as

$$U_B(x|\theta) = a - p_0 - (x - \theta). \quad (1)$$

The utility function of a customizer with preference θ is defined as

$$U_C(x|\theta) = a - p_0 - r(\theta - x). \quad (2)$$

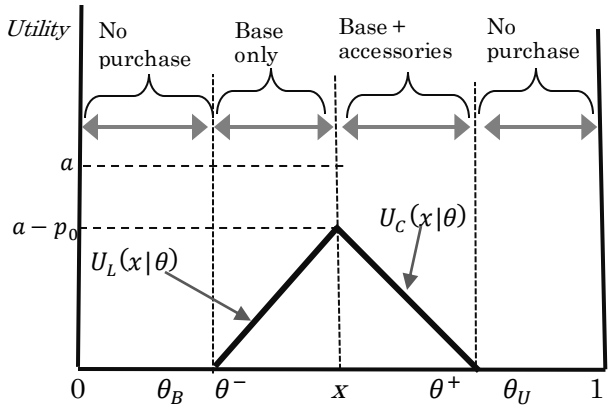

Figure 1: Utility functions and purchasing decisions.

In Eq. (1), a is an exogenously given constant, and p_0 is the price of the base product; it is assumed to be exogenously given. A fixed retail price is reasonable when competition in the market is intense and a price matching strategy or other marketing factors mean that the retail price is set at a generally accepted level. The term $x - \theta$ denotes the disutility due to the gap between the customer's preference θ and the quality level of the base product x. We assume this disutility is proportional to the quality gap. In Eq. (2), there is no disutility due to a mismatch between the consumer's preference and the product quality because we assume that such a gap can be overcome by customer customization. The third term of (2) represents the customer's extra payment to buy accessories that personalize the product. From tractability, we assume that payment for accessories is proportional to the quality level that the customer wants to increase. The parameter r denotes the unit payment that is necessary to increase a unit of quality level. The two bold lines in Figure 1 show our setting of these utility functions and the corresponding purchasing decisions of the customers.

2.3. Four cases with respect to target customers

We assume that a customer buys a product only when his or her utility is non-negative. Thus, this depends on the values of a and p_0, and there is a possibility that the utility function (1) or (2) becomes negative within the interval between θ_L and θ_U. Hence, the market range in which the base product is sold can be categorized into the following four cases:

Case 1: $\theta^- \le \theta_L < \theta_U \le \theta^+$.
Case 2: $\theta^- \le \theta_L < \theta^+ \le \theta_U$.
Case 3: $\theta_L \le \theta^- < \theta_U \le \theta^+$.
Case 4: $\theta_L \le \theta^- < \theta^+ \le \theta_U$.

Parameters θ^- and θ^+ denote the threshold values of θ that satisfy $U_B(x|\theta^-) = 0$ and $U_C(x|\theta^+) = 0$, respectively. Simple calculation determines the thresholds as

$$\theta^- = \theta^-(x) = p_0 - a + x, \text{ and} \quad (3)$$
$$\theta^+ = \theta^+(x) = (a - p_0)r^{-1} + x. \quad (4)$$

Figure 2 illustrates the locations of these four cases in the plane of x and $a - p_0$. Note that technically we do not set these four cases exclusively of each other (e.g., threshold values belong to more than one case).

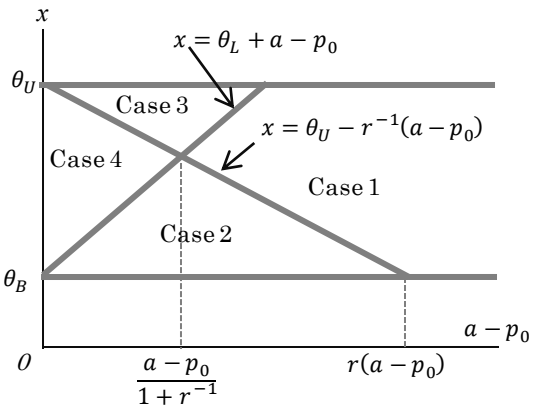

Figure 2: Four cases of the design.

2.4. Profit functions

We assume that the unit production cost of the base product is proportional to its quality level. Hence, the production cost is defined as $c_0 + cx$, in which $c_0 > 0$ is a given fixed cost and $c > 0$ is a coefficient of the variable cost that is proportional to the quality level x. We assume that c is small enough to always be $p_0 > c_0 + cx > 0$. We define the unit profit per unit quality that a firm can earn from the sale of accessories as α $(0 < \alpha < r)$, which means that the profit gained by an accessory is less than its retail price of it. Then, the profit functions where a decision variable is a quality level, x $(\theta_L \le x \le \theta_U)$, are defined as follows.

The profit function for the base users is

$$\pi_B(x) = (p_0 - c_0 - cx)(x - \max(\theta_L, \theta^-)). \quad (5)$$

The profit function for the customizers is

$$\pi_C(x) = (p_0 - c_0 - cx)(min(\theta^+, \theta_U) - x) + \alpha \int_x^{min(\theta^+, \theta_U)} (\xi - x) f(\xi) d\xi. \quad (6)$$

Note that the second term in Eq. (6) represents the total profit gained by selling accessories, where $f(\theta)$ represents the probability density function of the customer heterogeneity θ. When a uniform distribution over $[0,1]$ is assumed for θ, Eq. (6) can be rewritten as

$$\pi_C(x) = (p_0 - c_0 - cx)(min(\theta^+, \theta_U) - x) + 0.5 \cdot \alpha(min(\theta^+, \theta_U) - x)^2. \quad (7)$$

From Eqs. (5) and (7), the total profit of the manufacturer is determined as

$$\pi(x) = \pi_B(x) + \pi_C(x) = (p_0 - c_0 - cx)(x - \max(\theta_L, \theta^-)) + (p_0 - c_0 - cx) \cdot (min(\theta^+, \theta_U) - x) + 0.5 \cdot \alpha(min(\theta^+, \theta_U) - x)^2. \quad (8)$$

Note that our assumption that all customers located above x will buy accessories is not always true. Nevertheless, a reduction in the value of α can capture such a reduction in the number of accessory buyers. Thus, our assumption that all customizers buy accessories does not lose its generality.

3. MODEL ANALYSIS

3.1. Optimal quality level of the base product

Solving the first-order condition of the profit function (8), the optimal quality level x^* of the base product can be determined as follows.

Proposition 1. *The optimal quality of the base product x^* is determined as follows:*

(a) For Case 1 ($\theta^- \le \theta_B < \theta_U \le \theta^+$) where $x \le \theta_L + a - p_0$ and $\theta_U - r^{-1}(a - p_0) \le x$, $x^* = min[\theta_U - r^{-1}(a - p_0), \theta_L]$.

(b) For Case 2 ($\theta^- \le \theta_L < \theta^+ \le \theta_U$) where $x < \theta_L + a - p_0$ and $x < \theta_U - r^{-1}(a - p_0)$,

when $0 \le a - p_0 \le (1 + 1/r)(a - p_0)$,

If $(p_0 - c_0)/c - (a - p_0)/r \le \theta_L$, then $x^* = \theta_L$,

if $(p_0 - c_0)/c - (1 + r^{-1})(a - p_0)/r < \theta_L < (p_0 - c_0)/c - (a - p_0)/r$, then $x^* = \frac{\theta_L}{2} + \frac{p_0 - c_0}{2c} - \frac{a - p_0}{2r}$, and

if $\theta_L < (p_0 - c_0)/c - (1 + r^{-1})(a - p_0)/r$, then $x^* = \theta_L + a - p_0$, and

when $(1 + 1/r)(a - p_0) < a - p_0 \le r^{-1}(a - p_0)$,

If $(p_0 - c_0)/c - (a - p_0)/r \le \theta_L$, then $x^* = \theta_L$,

if $\theta_L < (p_0 - c_0)/c - (a - p_0)/r < 2\theta_U - \theta_L - (a - p_0)/r$, then $x^* = \frac{\theta_L}{2} + \frac{p_0 - c_0}{2c} - \frac{a - p_0}{2r}$, and

if $2\theta_U - \theta_L - r^{-1}(a - p_0) < (p_0 - c_0)/c - (a - p_0)/r$, then $x^* = \theta_U - (a - p_0)r^{-1}$.

(c) Case 3 ($\theta_B \le \theta^- < \theta_U \le \theta^+$) where $\theta_L + a - p_0 \le x$ and $\theta_U - (a - p_0)/r < x$, $x^* = min[\theta_U - r^{-1}(a - p_0), \theta_L + a - p_0]$.

(d) Case 4 ($\theta_L \le \theta^- < \theta^+ \le \theta_U$) where $\theta_L + a - p_0 \le x$ and $x < \theta_U - r^{-1}(a - p_0)$, $x^* = \theta_L + a - p_0$.

Proof. The solutions can be obtained by simple calculation of the first- and second-order conditions of Eq. (8) for the four cases.

One can reasonably interpret $\theta_U - \theta_L$ as the range of consumers that a firm targets in its marketing strategy, r as the retail price of accessories, and $a - p_0$ as the potential brand equity that the product possesses. For example, a large $\theta_U - \theta_L$ implies that the product is designed as a catch-all product, whereas a small $\theta_U - \theta_L$ indicates a niche product. In addition, a product with high brand equity results in a high $a - p_0$, whereas this value is low for a product of generic brand equity. Figure 3 is a visualization of Proposition 1. The optimal quality levels of the four cases are drawn in the coordination of quality level x and the potential brand equity $a - p_0$.

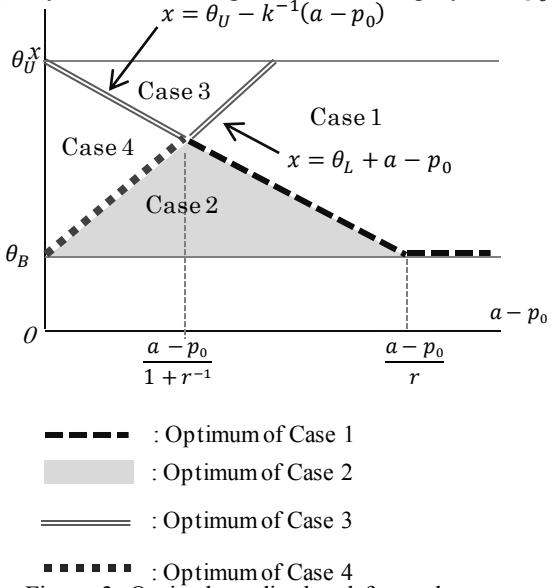

Figure 3: Optimal quality level for each case.

From Figure 3, the followings are implied. When $a - p_0$ is sufficiently high, the optimal quality level will be the lowest of the target market (i.e., $x^* = \theta_L$ in Case 1). This implies that the base model should be as simple as possible if its brand equity is high. Harley-Davidson motorcycles could fall into this category: the firm offers customers a base motorcycle that the loyal owners can then personalize as they like. In contrast, when $a - p_0$ is sufficiently low (i.e., Case 4), the optimal quality level of the product is not fixed, depending on the brand equity level ($a - p_0$). In general, we know from Proposition 1 (d) that in Case 4 more functionality of the base model is required as its equity increases. This is also intuitive. In a certain product category, such as consumer electronic appliances, it is common that a product with a brand name has more product features than a generic product.

Next, we discuss the implications of a firm targeting only a small portion of the market range $[\theta_L, \theta_U]$ (i.e., a focus strategy). Proposition 1-c implies that when a firm targets only high-end users whose preference is close to θ_U (i.e., Case 3), the product should be designed to be at the minimum level of the target area (i.e., the bold double line in Figure 3). Proposition 1-d can be interpreted as suggesting that the optimal quality level of a product targeting low-end users (i.e., Case 2) should be determined by examining the market situation (i.e., the gray area in Figure 3 could be the optimum).

In general, it is safe to say that a decision of base product quality is relatively easy when the brand equity is quite high or when the target market is high-end users. However, careful consideration may be required when the product is designed to target low-end users because, in such a case, a wide range of possibility exists in the determination of quality level.

So far, we have considered the optimal decision for each case. However, the case-dependent optimum can be rewritten as a more generalized form. For example, the optimal solution for Case 3 is the lowest level of x in the region of Case 3; however, this optimal solution is shared by Cases 1, 2, and 4 because our categorization of cases is not exclusive. Proposition 2 shows the general expression of the optimal quality design.

Proposition 2. *The optimal quality of the base product is determined as*

(a) when $0 \le a - p_0 \le (1 + 1/r)(a - p_0)$,

If $(p_0 - c_0)/c - (a - p_0)/r \le \theta_L$, *then* $x^* = \theta_L$,

if $(p_0 - c_0)/c - (1 + r^{-1})(a - p_0)/r < \theta_L < (p_0 - c_0)/c - (a - p_0)/r$, *then* $x^* = \frac{\theta_B}{2} + \frac{p_0 - c_0}{2c} - \frac{a - p_0}{2r}$, *and*

if $\theta_L < (p_0 - c_0)/c - (1 + r^{-1})(a - p_0)/r$, *then* $x^* = \theta_L + a - p_0$, *and*

(b) when $(1 + 1/r)(a - p_0) < a - p_0 \le r^{-1}(a - p_0)$,

If $(p_0 - c_0)/c - (a - p_0)/r \le \theta_L$, *then* $x^* = \theta_L$,

if $\theta_B < (p_0 - c_0)/c - (a - p_0)/r < 2\theta_U - \theta_L - (a - p_0)/r$, *then* $x^* = \frac{\theta_B}{2} + \frac{p_0 - c_0}{2c} - \frac{a - p_0}{2r}$, *and*

if $2\theta_U - \theta_L - r^{-1}(a - p_0) < (p_0 - c_0)/c - (a - p_0)/r$, *then* $x^* = \theta_U - (a - p_0)r^{-1}$.

(c) when $r^{-1}(a - p_0) < a - p_0$, *then* $x^* = \theta_L$.

Figure 4 illustrates the trajectories of the optimal quality decision for the base product in the x and $a - p_0$ planes. Note that the trajectory of the optimal quality $x^* = x^*(a - p_0)$ is categorized into three scenarios, as shown by the three bold lines in Figure 4. The trajectory of Scenario A first increases in $a - p_0$, following the line of $x = \theta_L + a - p$. It then decreases following $x = \theta_U - r^{-1}(a - p_0)$ and finally remains at θ_L. In Scenario C, the trajectory always remains at the minimum quality level θ_L. The trajectory of Scenario B is located between that of Scenarios A and C.

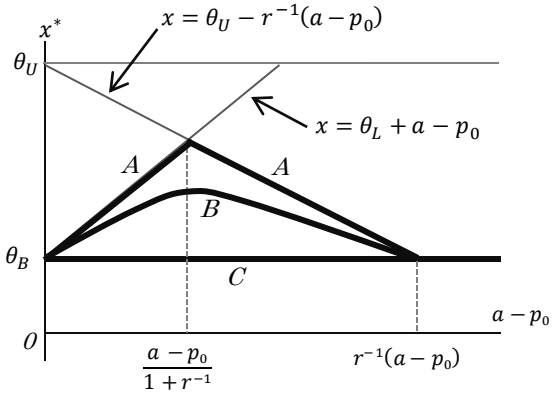

Figure 4: Trajectory of optimal quality.

Proposition 2 and Figure 4 imply that when the margin of the base product is relatively low, brand equity is sufficiently high, and the target market covers relatively high-end users. (i.e., for the situation satisfying $(p_0 - c_0)/c - (a - p_0)/r \le \theta_L$), the base product should be designed with as low a quality as possible. Then, the firm should earn profits through the sale of accessories. In other words, the razor and razor blade model is applicable in such a situation. In contrast, if the profit margin is relatively high, brand equity is relatively low, and the target market focuses on relatively low-end users, the quality of the base product should be greater than the base level. In such a case, the product should be designed to be a so-called "all-in-one" type, in which many functionalities and features are pre-installed and customer customization after purchasing is low. In the personal computer (PC) category, PCs for novice users are often designed to be of the all-in-one type. Our analysis gives a general rule of thumb for a product design strategy.

3.2 Sensitivity analysis

This subsection examines the sensitivity of the optimal solutions with respect to several key parameters α, r, and p_0 and discuss how generic products offered by third-parties may influence the optimal design of the base product of the brand manufacturer.

Proposition 3. *(a)* x^**is independent of* α*. (b)* $\partial x^*/\partial r \geq 0$*. (c)* $\partial x^*/\partial p_0 \geq 0$.

Proof. From Proposition 1, (a) is self-evident; (b) $\partial x^*/\partial r = either\ \ 0, (a-p_0)/2r^2, or\ \ (a-p_0)/r^2$; and (c) $\partial x^*/\partial p_0 = either\ \ 0, 1/2c + 1/2r, or\ \ (1+r^{-1})/r$.

The interpretations of Proposition 3 are as follows.

Effect of a unit profit that the sale of accessories (α): Proposition 3-a is related to the effect of third-party competitors on the optimal product design x^* of the base product of the brand manufacturer. One knows from the profit function (8) that the unit profit of selling accessories α will be reduced as customers switch to generic products. Hence, the availability of generic products may undermine the profitability of the brand firm. However, the optimal values in Proposition 1 do not contain α. Therefore, even though the profitability of accessories of the brand firm declines when competition against low-price generic accessories from the third parties is intensified (e.g., costs associated with increased advertising by the brand firm to compete with third parties), we conclude that, within our framework, there is no need to change the design of the base product.

Effect of accessory pricing (r): It is natural that the price of brand accessories may be influenced by low-priced generic accessories. Therefore, we examine the sensitivity of the optimal design with respect to the price of the brand accessories r. Proposition 3 shows that as r decreases, x^* also decreases or at least remains the same. This implies that if competition with low-price generic products forces the brand firm to reduce its retail price, the firm should, at the same time, redesign the base product to be of low quality.

Effect of base retail price of the base product (p_0): Finally, we analyze the effect of the retail price of the base product on its design. Here we focus on its fixed price p_0. It is intuitive that the optimal quality level of the base product decreases with the retail price p_0; this is intuitive. In addition, the sensitivity with respect to r and p_o implies the possibility that low-price third-party products will give rise to brand firm pressure to reduce both the price and quality of the brand product.

3.3. Retail price is proportional to quality level

So far, we have assumed that the retail price is fixed at p_0 and is irrelevant to the quality level of the base product. This setting is reasonable in a situation in which competition with rival firms is severe, or where retailers have the power to control the retail products. However, another reasonable setting is that the retail price increases with the quality of the products. This subsection examines how the optimal quality of the base product is influenced if its retail price is an increasing function of the quality level: $p_0 = p_0(x)$ and $\partial p_0/\partial x > 0$. Figure 5 is a numerical example showing how the optimal quality x^* and the corresponding total profit $\pi(x^*)$ change when the retail price is proportional to the quality level, $p_0(x) = p_0 + px$, and the variable price p changes. In Fig. 5, the parameter values are arbitrarily set as $\theta_L = 0.10$, $\theta_L = 0.80$, $a = 1.2$, $r = 0.8$, $c_0 = 0.2$, $c = 0.01$, $p_0 = 1$, and $p = 0.00, 0.05, 0.10, 0.15, 0.20, 0.25\ or\ 0.30$.

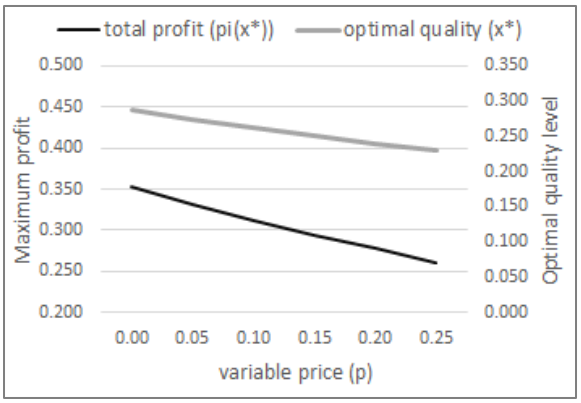

Figure 5: Optimal quality (x^*) and the corresponding profit with respect to variable price (p).

We know from Figure 5 that as the price increases due to quality enhancement is more sensitive (i.e., higher p), the optimal quality level x^* and the corresponding total profit decrease. This can be interpreted as a higher price discouraging customers from buying the product; thus, negatively impacting the optimal quality level and the corresponding profit. We conclude from this numerical example and Proposition 3 that it is reasonable for a firm to maintain the price of a base product at a certain level and earn profit by selling accessories rather than by selling the base product.

4. MANAGERIAL IMPLICATIONS

Here, we summarize the managerial implications derived from the analytical results.

- When brand equity is sufficiently high, the base product should be designed as a simple platform that users can customize as they like using accessories and optimal items (implication from Proposition 1-a).
- When brand equity is sufficiently low, or when the firm targets low-end users, the quality of the base product

should be greater than the minimum level. In other words, considering the market environment, the firm should determine a greater than minimum level of quality to gain customer demand and profit (implication from Proposition 1-b and 1-d).

- When targeting high-end users, the base product should be designed to be of the lowest quality level that the target users will accept (implication from Proposition 1-c).
- Although the existence of third-party products might influence profitability and retail price, decisions related to the optimal quality level of the base product are not sensitive as long as the design is determined based on consumer preference (implication from Proposition 3).
- The razor and razor blade model is reasonable, i.e., a firm maintaining the price of a base product at a certain level and earning profit by selling accessories (implication of the numerical example in Section 3.3).

The implications above give management insights into the adoption of a razor and razor blade model, especially in terms of how to determine the quality level of a base durable product. The key to the success of using the razor and razor blade model is to maximize the accessory purchasing of the customers. In general, in such a case, a low functionality of the base item is preferable for a brand firm, whereas a certain level of quality is required for the base product of a generic firm with low brand equity.

5. CONCLUDING REMARKS

It is not uncommon that users of certain durable products customize the product by attaching accessories and optional items after purchase. At the same time, the sale of accessories and consumable products, rather than of the main durable product itself, is often the source of profit in a modern manufacturing environment. Such a sales strategy is sometimes called a razor and razor blade model. This paper studied how a firm should determine the quality level of a durable product that users personally customize with accessories after purchase when the firm can earn profit not from the sale of the main product but via the sale of accessories. An analytical model determined the optimal quality decisions by categorizing the model settings into four cases, and we provided the several managerial implications derived from the analytical results. The key of base product design of a brand product is to keep quality at the lowest level; however, for a low brand name firm, it is necessary to set the quality and functionality of the product above the minimum level.

There remains a potential for future research in this area, for example, by relaxing several assumptions, such as the linearity assumption of the heterogeneity of customers' preferences or the cost of adding quality to the product. Another direction could be to explicitly include competition between the brand and third-party firms using a game model. In addition, the effect of the timing of accessory purchases (e.g., at the time of buying the main product vs. after purchasing the main product) is an interesting theme that could be developed in future research.

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