When Technology Products Meet Social Needs: Product Pricing and Design

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Recent technological advances have created unprecedented opportunities for consumer technology products to assume a new role, that of representing users' social status. We study how social-reference-group effects impact firms' product pricing, design, and targeting strategies. We find that, in a commonly-adopted strategy, *Sequential Adoption*, where early adopters (leaders) upgrade to a new version when new customers (followers) arrive and adopt the original version, a firm could benefit by leveraging a *push* effect on leaders who desire to escape from using the same version as followers. However, a strong reference-group effect can also hurt the firm due to a *pull* effect from the new version on followers who desire to assimilate with leaders. We then study how the firm should differentiate its product versions in two dimensions, functionality and exterior appearance, by leveraging the reference-group effect. We identify three optimal design policies: *Functional-Only Differentiation*, *Joint Differentiation*, and *Exterior-Focused Differentiation*, which differ in the firm's focus on the two design dimensions. Two factors, the strength of the reference-group effect and the base functional value of the product, jointly determine the conditions under which each design policy dominates the others.

Key words: reference-group effect; cross-version competition; product design; exterior form; functionality

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1. Introduction

> "For many people, a laptop may be just as much an everyday accessory as a hip belt or skyscraper stilettos, so we are seeing an image-conscious culture demanding that their laptop looks as great as it performs." (Steven Cojocaru, style expert, intel.com, *Intel Press Release* 2005).

Consumer electronics companies have traditionally focused on introducing new products with either more advanced technology or lower prices. In recent years, however, increasing attention has been paid to the "social function" (the style or exterior design) of technology products such as laptop

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computers, cell phones, and digital cameras. A study by Intel and Ultrasuede found that "73 percent of U.S. adult computer users desire technology products that reflect their *personal style* and 76 percent of those computer users who admit to glancing at someone else's laptop PC are checking out its *style or design*" (*Harris Interactive* 2005). Such a trend did not emerge by accident; rather, it is the consequence of advances in technology that have both significantly decreased the cost of high-tech consumer products and considerably reduced the size of many electronic gadgets. While the former makes technology products more affordable to the mass market, the latter makes them more portable/wearable, both of which facilitate consumption in front of others. These changes are creating unprecedented opportunities for technology products to assume a new role, as an indicator of users' social status, in addition to satisfying their functional needs.

This emerging role of technology products is changing the perception and practice of high-tech firms' new product strategies. Many firms are making increasing efforts to integrate fashion into their products. While the success of Apple's iPad, iPod and iPhone relies on their functional excellence, it is also due in part to their innovative style. In addition, many technology companies have resorted to partnerships with fashion icons to co-develop new products. For example, Hewlett-Packard partnered with world-renowned fashion designer Vivienne Tam to design the first "digital clutch," and LG Electronics has initiated a partnership with Prada, one of the most influential fashion houses, in designing cell phones.

As the marketplace is becoming increasingly fertile for integrating technology and fashion, academic attention to such integration is of both importance and urgency. Liebenstein (1950) highlighted the importance of social factors in consumption by categorizing consumption needs as functional and non-functional. Extensive research shows that consumers have a tendency to engage in social comparisons (upward assimilation and downward differentiation), and such comparisons influence consumers' evaluations of products (Bearden and Etzel 1982, Belk 1988, Brewer 1991). Recent developments in the marketing literature have advanced our understanding of the concept of the reference-group effect. Amaldoss and Jain (2005a, 2005b, 2008) specifically model the reference-group effect between two types of consumer (with a positive or negative social utility from a product when members of the reference group consume a similar product). The reference-group effect is a double-edged sword: It increases the product value for some consumers (followers) who like to emulate other consumers (leaders) and derive a positive social value when adopting a popular product, but decreases the product value for leaders who like to differentiate from followers and derive a negative social value when followers adopt a similar product.

In this paper, we examine how the combination of functional and social values affects firms' sequential product introduction strategies in the presence of such reference-group effects. Specifically, we study 1) the optimal pricing scheme, i.e., how the firm should price its products in the presence of such reference-group effects; 2) the optimal design policy, i.e., how the firm should design and differentiate the product variants in two dimensions, (a) functional improvement, which determines the product's functional value, and (b) exterior differentiation, which affects the product's social value; and 3) the optimal targeting strategy, i.e., how the firm should target different product versions at different consumer segments.

Our analysis offers several interesting insights. We first study the *Sequential-Adoption* strategy where leaders upgrade to a newly introduced version of a technology product, and followers adopt the original version. We find that the firm could benefit from the reference-group effect, but may also suffer if it becomes too strong. This nonlinear impact of the reference-group effect on profit is driven by its opposite impacts on leaders' and followers' social utility and by potential cross-version competition between the original and new versions for leaders and/or followers. The negative reference-group effect on leaders as a result of followers' adoption of the original version can "push" leaders to upgrade to the new version and consequently can increase the firm's profit. This *push* effect arises when cross-version competition for leaders exists, i.e., when the reference-group effect is relatively weak. When it is strong, however, cross-version competition for followers emerges. Leaders' adoption of the new version can make the latter more attractive to followers, and thus "pulls" followers away from the original version. This *pull* effect increases the cost of the *Sequential-Adoption* strategy, thereby decreasing the firm's profit.

Second, we also provide insights into how the firm should optimally differentiate its product versions when its products offer both functional and social value to consumers (i.e., in the presence of the reference-group effect). We identify three optimal design policies that differ with regard to the firm's focus on the two design dimensions (functional and exterior differentiation): 1) *Functional-Only Differentiation*, 2) *Joint Differentiation*, and 3) *Exterior-Focused Differentiation*. Our results reveal that, as the reference-group effect increases, it is optimal for the firm to shift the focus of the new version design from functionality enhancement to exterior differentiation.

Interestingly, in markets with a weak reference-group effect, it is not profitable to differentiate product versions in exterior appearance (i.e., *Functional-Only Differentiation* is optimal); also, in markets with a very strong reference-group effect, although the firm benefits from differentiating the new from the original version in both dimensions, the firm will gain higher profits by increasing the differentiation level only in exterior appearance, but not in functionality, as the reference-group effect becomes stronger (i.e., *Exterior-Focused Differentiation* is optimal). The firm maximizes profit by introducing a new version with both enhanced functionality and altered exterior appearance only in markets with an intermediate reference-group effect, and the stronger this effect is, the higher is the differentiation level in both dimensions (i.e., *Joint Differentiation* is optimal). These findings underscore the importance for firms to understand the existence and the extent of the social functions their products may offer, and take them into consideration in the product design.

Finally, we extend our analysis of the *Sequential-Adoption* strategy to two other targeting strategies that the firm can consider: *Simultaneous Adoption,* under which the new version targets both leaders and followers, and *Leap-Frog Adoption*, under which the new version targets followers only. Our results show that, in the presence of the reference-group effect, each of the three targeting strategies can dominate others depending on the technology and social characteristics of the product. Specifically, if the functional value of the current version is not too high, such that further functional improvement is still cost-efficient, it is profitable to design and price the new version to attract leaders via two possible strategies: leaders only (i.e., *Sequential Adoption*) if the product offers consumers either very high or very low social value; leaders and followers together (i.e., *Simultaneous Adoption*), otherwise. In markets where the current version already offers a greatly advanced functional value, however, it is more profitable for the firm to strategically design and price the new version to attract followers, even at the cost of foregone revenue from leaders' upgrades (i.e., *Leap-Frog Adoption*). Our results illustrate that, as consumers become increasingly interested in the social function of technology products, it is important for firms to incorporate cross-segment social interactions in firms' optimal targeting strategies.

This paper makes several research contributions. First, it advances the literature on reference-group effects. Amaldoss and Jain (2005a, 2005b) precisely model reference-group effects (i.e., leaders' wish to distinguish themselves from followers and followers' desire to assimilate with leaders) and show that such effects play an important role in firms' pricing strategies. Several recent studies have examined how cross-segment social interactions affect firms' optimal market-entry timing decisions (Joshi et al. 2009), limited-edition strategies and simultaneous introduction of multiple undifferentiated products (Amaldoss and Jain 2008, 2010). Our study extends this stream of research to firms' new product design policies and targeting strategies. We study how firms should adjust their product design in both functionality and exterior appearance as technology products become increasingly important in serving consumers' social needs. We also offer insights into firms' product targeting strategies for different product categories, as characterized by the relative importance of social and functional needs.

Second, this paper contributes to the product design literature by incorporating reference-group effects into product design considerations. One important stream of literature has studied quality design issues of product lines in the presence of heterogeneous consumers with respect to their quality appreciation (e.g., Desai 2001, Mussa and Rosen 1978, Moorthy 1984). Some research has used conjoint models to select the functional characteristics (Chen and Hausman 2000, Ofek and Srinivasan 2002, Luo 2011). Others have studied the incorporation of consumers' subjective characteristics into product design (Luo et al. 2008). We capture the new role that technology products have assumed by modeling both functionality and exterior style. Exterior style carries symbolic meanings among consumers (Bloch 1995, Creusen and Schoormans 2005, Kreuzbauer and Malter 2005, Muller 2001, Solomon 1983). Social value is also an important component of consumption value (Sheth et al. 1991). Our results underscore the importance for technology firms to coordinate the optimal design along both dimensions, increments in functionality and differentiation in exterior form, when their products offer both functional and social values.

Third, we contribute to the literature on fashion goods by examining the role of functional value. Typically, the fashion literature has studied bandwagon and snob effects (Bagwell and Bernheim 1996, Bernheim 1994, Simmel 1904, Simmel 1957). In particular, Miller et al. (1993) and Pesendorfer (1995) studied the dynamics of the fashion process due to social interactions. We incorporate functional value into consumers' purchase decisions, and examine the interplay between functional and social values.

Finally, we contribute to the product-line literature by investigating the impact of reference-group effects across consumer segments. Prior literature has studied network externalities in firms' sequential product introduction decisions (e.g., Choi 1994, and Padmanabhan et al. 1997), product line extension strategies (Sun et al. 2004), and primary and secondary product strategies (Chen and Xie 2007). We look at two cross-group network externalities, one negative and one positive, in consumers' social motives for adopting products, and study how this may influence firms' product differentiation strategies.

The paper is organized as follows. In Section 2, we describe the model. In Section 3, we study the most commonly observed innovation strategy, *Sequential Adoption*, by deriving the firm's optimal pricing and the optimal product design. In Section 4, we examine the firm's optimal product targeting strategy by comparing three potential targeting strategies: *Sequential Adoption, Simultaneous Adoption*, and *Leap-Frog Adoption*. We discuss managerial implications and conclude the paper in Section 5. We provide proofs in Appendix, and additional results in the on-line supplement.

2. Model Development

2.1. The Product

In contrast with the extant literature, we consider a durable product with two characteristics: functionality and exterior appearance. The product provides functionality to satisfy consumers' material needs, such as the need for data storage, graphical processing, and so forth. Exterior features provide a communication mechanism that can be observed by consumers and can facilitate social interaction. For ease of exposition, we associate exterior form with reference-group effects, and functionality with inherent value, which allows us to separate the effects of functionality and exterior form in firms' strategies.[6]

We examine a firm's sequential product introduction strategy and consider two time periods. An original version, denoted by o, is available in both periods. In the second period, the firm has an option to introduce a new version, denoted by n. The new version can be differentiated from the old version in two dimensions, incremental functionality and exterior design. The intrinsic functional value of version $j \in \{o, n\}$ is given by v_j, where $v_o = v$, $v_n = v + \Delta$, and Δ is the incremental functionality of the new version. In this paper, we refer to v as the base functional value. The exterior differentiation of the two versions is measured by $d \in [0,1]$. A higher value of d indicates a

[6]We simplify our model by considering only the social value conveyed by exterior form and suppressing the aesthetic values it may provide (Bloch 1995, Kreuzbauer and Malter 2005). We make such simplification because our focus here is on cross-social-group comparisons.

greater exterior differentiation. When $d \to 0$, the two product versions appear almost identical. When $d \to 1$, the two versions have almost no commonality in appearance. A summary of our notations can be found in Table 1.

Table 1. Notations

Notation	**Meaning**
α	Leader segment size
$1-\alpha$	Follower segment size
v	Leaders' functional valuation of the original version
βv	Followers' functional valuation of the original version
$v + \Delta$	Leaders' functional valuation of the new version, where Δ is the incremental functional value
$\beta(v + \Delta)$	Followers' functional valuation of the new version
d	Exterior differentiation between two versions
r	Strength of the reference-group effects
$p_{o,1}$	Original version's price in period 1.
$p_{j,2}$	Price for version $j \in \{o, n\}$ in period 2 (later simplied to p_j for convenience)
δ	Discount factor of consumers and the firm
c	Unit product cost per unit of intrinsic value
K	Fixed product development cost $K = k_1\Delta^2 + k_2 d^2$

2.2. The Consumer

The market, the size of which is normalized to unity, consists of two segments of consumers, leaders and followers, denoted by l and f, with α and $1-\alpha$ in proportion, respectively. Following the literature (Amaldoss and Jain 2005a, 2005b, 2008, 2010, Becker and Murphy 2000, Stock and Balachander 2005), leaders arrive in the first period, and followers arrive in the second period. Leaders wish to be distinct from followers, whereas followers wish to conform to leaders. They argue that leaders enter the market earlier because of their higher social position and discerning taste, and followers enter later because of their conforming needs.

Following Amaldoss and Jain (2005a, 2008, 2010), we assume that consumers derive functional utility from products' functionality and social utility (or disutility) by comparison with a reference group. The net utility of a consumer of type $i \in \{l, f\}$ by consuming a product of version $j \in \{o, n\}$ priced at $p_{j,t}$, in period $t \in \{1,2\}$, and by observing the reference group i' using version j', is given by

$$U_{i,j,i',j',t} = v_{i,j} + g_{i,j,i',j',t} - p_{j,t}. \quad (1)$$

The first term, $v_{i,j}$, is type i consumers' functional valuation of product version j, which is assumed to be proportional to the product's intrinsic functional value. Without loss of generality, we normalize the leaders' valuation to be equal to the product's intrinsic functional value. Hence, leaders' valuation $v_{l,o}$ of the original version and valuation $v_{l,n}$ of the new version are respectively given by

$$v_{l,o} = v, \text{ and } v_{l,n} = v + \Delta. \tag{2}$$

Followers' valuation $v_{f,j}$ of version $j \in \{o, n\}$ is given by

$$v_{f,o} = \beta v, \text{ and } v_{f,n} = \beta(v + \Delta), \tag{3}$$

where $\beta \leq 1$ reflects the fact that followers are less sensitive to technology advancement.

The second term, $g_{i,j,i',j',t}$, in equation (1) is consumer type i's social (dis)utility when reference group i' is using product version j' in the same time period t. The magnitude of such social (dis)utilities is affected by the following factors: 1) the number of users $n_{i'}$ in the reference group; 2) the strength r of the reference-group effects; and 3) the exterior distinction d between the versions used by the two consumer types. We explain leaders' and followers' social (dis)utility in detail below.

Leaders wish to distinguish themselves from followers. Hereafter, we term this effect *Reforming Need*. Leaders, using product version j in period t, derive a social disutility, $g_{l,j,f,j',t} \leq 0$, when they see followers using product version j' in the same period. Leaders' social disutility reflects the extent to which they wish to demonstrate their "social distance" from followers. The exterior differentiation, $d \in [0,1]$, between the versions used by the two consumer types, plays the following role in leaders' social disutility. When the outward appearance of two product versions is almost identical, i.e., $d \to 0$, or when they are using the same version, leaders' ability to distinguish themselves from followers is minimal and, hence, they suffer from the strongest social disutility. When the two versions look completely different, i.e., $d \to 1$, it helps leaders distinguish themselves from followers to the maximum possible extent. Otherwise, the leaders' social disutility is moderated by a factor of $1 - d$. In sum, we have

$$g_{l,j,f,j',t} = \begin{cases} -r \cdot n_f & \text{if } j = j' \\ -r \cdot (1-d) \cdot n_f & \text{otherwise'} \end{cases} \tag{4}$$

where the number of followers $n_f = 0$ in period $t = 1$, and $n_f = 1 - \alpha$ in period $t = 2$.

Followers wish to conform to leaders, and we term this effect the *Conforming Need*. Followers, using product version j, derive a social utility, $g_{f,j,l,j',t} \geq 0$, when they see leaders using product version j' in the same period t. The strength of followers' social utility reflects the extent to which they wish to mimic the leaders. When the two versions look almost identical, i.e., $d \to 0$, or when they are using the same version as leaders, followers enjoy the strongest social benefits as they mimic leaders to the maximum possible extent. When the two versions are completely different, i.e., $d \to 1$, followers can hardly mimic leaders. Otherwise, followers' social utility is moderated by a factor of $1-d$. In sum, followers' social utility in period 2 is given by

$$g_{f,j,l,j',2} = \begin{cases} r \cdot n_l & \text{if } j = j' \\ r \cdot (1-d) \cdot n_l & \text{otherwise} \end{cases}. \tag{5}$$

where the number of leaders $n_l = \alpha$.

In sum, leaders' net utility from the original version in period 1 (in the absence of followers) is given by

$$U_{l,1} = v - p_{o,1}, \tag{6}$$

leaders' net utility from keeping the original version in period 2 is given by

$$U_{l,o,f,j',2} = \begin{cases} v - r \cdot (1-\alpha) & \text{if } j' = o \\ v - r \cdot (1-d) \cdot (1-\alpha) & \text{otherwise} \end{cases}, \tag{7}$$

and leaders' net utility from upgrading to the new version in period 2 is given by

$$U_{l,n,f,j',2} = \begin{cases} v + \Delta - r \cdot (1-\alpha) - p_{n,2} & \text{if } j' = n \\ v + \Delta - r \cdot (1-d) \cdot (1-\alpha) - p_{n,2} & \text{otherwise} \end{cases}. \tag{8}$$

Followers' net utility from adopting the original version in period 2 is given by

$$U_{f,o,l,j',2} = \begin{cases} \beta v + r \cdot \alpha - p_{o,2} & \text{if } j' = o \\ \beta v + r \cdot (1-d) \cdot \alpha - p_{o,2} & \text{otherwise} \end{cases}, \tag{9}$$

and followers' net utility from adopting the new version in period 2 is given by

$$U_{f,n,l,j',2} = \begin{cases} \beta(v+\Delta) + r \cdot \alpha - p_{n,2} & \text{if } j' = n \\ \beta(v+\Delta) + r \cdot (1-d) \cdot \alpha - p_{n,2} & \text{otherwise} \end{cases}. \tag{10}$$

Each consumer has at most one unit of demand for the product in each period. For simplicity, we assume that the product has no resale value and consumers can dispose of used products at no cost. In each period, consumers decide whether or not to adopt or upgrade the product. The consumers and the firm have a common discount factor δ.

2.3. The Firm

The firm makes several decisions, including optimal price, design policy and targeting strategy. The firm determines an optimal price $p_{o,1}$ for the original version in period 1, and an optimal price $p_{j,2}$ for version j that is available in period 2. (For convenience, we simplify the notation of the original version's price in the second period as p_o, and the new version's price in the second period as p_n.)

The firm incurs a unit cost vc to produce the original version, and a unit cost $(v + \Delta)c$ to manufacture the new version.[7]

When the firm introduces a new product version, it must decide its design policy, an incremental functionality Δ and exterior differentiation d. The development of the new version incurs a fixed cost $K = k_1\Delta^2 + k_2 d^2$, which is convex, increasing in Δ and d, respectively.

The firm must decide its targeting strategy in the second period, i.e., whether or not to introduce a new version and, if so, which consumer segment(s) the new version should target. Specifically, the firm has three alternatives: 1) The *Sequential-Adoption* strategy, where leaders adopt the new version and followers adopt the original version; 2) The *Simultaneous-Adoption* strategy, where both leaders and followers adopt the new version; and 3) The *Leap-Frog-Adoption* strategy, where leaders keep using the original version and followers adopt the new version. We will first focus on the most widely adopted strategy in practice, *Sequential Adoption*, in Section 3. We then discuss when each of the above targeting strategies becomes optimal in Section 4. Analyses of the other targeting strategies are discussed in the online supplement.

3. Analysis of the *Sequential-Adoption* Strategy

Under the *Sequential-Adoption* strategy, the firm sets prices such that leaders upgrade to the new version and followers adopt the original version. In Section 3.1, we derive the optimal prices for the two versions, given a set of design parameters (i.e., the incremental functionality parameter, Δ, and the exterior differentitation parameter, d). In Section 3.2, we focus on optimal product design.

3.1. Pricing and Profit Strategies Given the Product Design

In this section, we derive the firm's optimal pricing and profits, and discuss how the reference-group effect (r) and the two dimensions of the product design (Δ, d) jointly affect profit under the *Sequential-Adoption* strategy.

When a new version becomes available, leaders have three choices: 1) Stay with the original version at no additioal cost; 2) upgrade to the new version at a price p_n; or 3) dispose of the original version without upgrading. Followers also have three choices: 1) Adopt the original product at a price

[7]Note that the unit cost is independent of the exterior appearance because we caputre only its social value (a function of exterior differentiation between two versions), but not its aesthetic value.

p_o; 2) adopt the new product at a price p_n; or 3) adopt neither. By definition, under the *Sequential-Adoption* strategy, the optimal prices for the two versions will be the highest prices under which leaders choose to upgrade and followers choose to adopt the original product.

For convenience, redenote leaders' utility in the second period under the *Sequential-Adoption* strategy from the original and new versions by $U_{l,o} = v - r(1-\alpha)$, i.e., equation (7), and $U_{l,n} = v + \Delta - r(1-d)(1-\alpha) - p_n$, i.e., equation (8), respectively, and followers' utility from the original and new versions by $U_{f,o} = \beta v + r(1-d)\alpha - p_o$ i.e., equation (9), and $U_{f,n} = \beta(v+\Delta) + r\alpha - p_n$, i.e., equation (10), respectively. The firm maximizes its net profit, i.e., total discounted revenue from two periods net the cost,

$$\pi = \alpha p_{o,1} + \delta[\alpha p_n + (1-\alpha)p_o] - C \tag{11}$$

subject to

$$v - p_{o,1} \geq 0 \tag{12}$$

$$U_{l,n} \geq 0 \tag{13}$$

$$U_{l,n} \geq U_{l,o} \tag{14}$$

$$U_{f,o} \geq 0 \tag{15}$$

$$U_{f,o} \geq U_{f,n} \tag{16}$$

where $C = \alpha vc + \delta[\alpha(v+\Delta) + (1-\alpha)v]c$ is the total production cost. In the following, we use *P* to refer to the participation constraint, and *IC* to refer to the incentive-compatibility constraint. Equation (12) above is leaders' *P* constraint for adopting the original version in the first period. Under the rational-expectation equilibrium assumption, leaders will anticipate that the firm will subsequently introduce a new version, and price the two versions such that they will choose to upgrade to the new version. Consequently, they are willing to pay only for the utility rendered in the first period, i.e., constraint (12) must be binding. Hence, the optimal price of the original version in the first period is given by $p_{o,1} = v$.

Equations (13) and (14) are leaders' *P* and *IC* constraints for upgrading to the new version in the second period, respectively. Equations (15) and (16) are followers' *P* and *IC* constraints for adopting the original version in the second period, respectively. A binding *IC* constraint indicates a competition effect between the two product versions, i.e., both versions offer a positive value to the corresponding consumer segment, and thus compete with each other. Specifically, the *IC* constraint for leaders (14) implies that, in order to motivate leaders to adopt the new version rather than stay with the original, the price of the new version must be sufficiently low that leaders receive a higher utility by switching to the new version. The binding *IC* constraint for followers (16) implies that, to induce followers to purchase the original rather than adopt the new version, the price of the former must be sufficiently low that followers receive a higher utility from the original than from the new version. A binding *P* constraint indicates that such a competition effect is absent. Specifically, the binding *P* constraint for leaders (13) implies that the price of the new version is determined by leaders' utility from the new version only, and the binding *P* constraint for followers (15) implies that the price of the original version is determined by followers' utility from the original version only.

At optimal prices, for each segment, either their *P* constraint or their *IC* constraint must be binding. Together, there are four possible optimal pricing schemes: 1) Leaders' *IC* and followers' *P* constraints are binding, denoted *IC-P*; 2) both leaders' and followers' *IC* constraints are binding, denoted *IC-IC*; 3) both leaders' and followers' *P* constraints are binding, denoted *P-P*; and 4) leaders' *P* and followers' *IC* constraints are binding, denoted *P-IC*. Lemma 1 presents the four optimal pricing schemes and the corresponding conditions required for each to dominate the others.

Lemma 1 (Optimal Pricing)

Under the Sequential-Adoption strategy, the firm has four possible pricing schemes depending on the specific binding constraints (IC or P) for the specific consumer segments (leaders or followers). The following table specifies the four pricing schemes and the conditions under which each pricing scheme is optimal:

<table>
<tr><th>Four Possible Pricing Schemes</th><th>Conditions</th></tr>
<tr><td>IC-P : $\begin{cases} p_n^{(IC-P)} = \Delta + rd(1-\alpha) \\ p_o^{(IC-P)} = \beta v + r(1-d)\alpha \end{cases}$</td><td rowspan="4">$\begin{cases} IC-P \ and/or \ IC-IC & \text{for } r \le r_1 \\ P-P & \text{for } r \in (r_1, r_2] \\ P-IC & \text{for } r > r_2 \end{cases}$

where, $r_1 = \frac{v}{1-\alpha}$ and

$r_2 = max\left[\frac{(1-\beta)(v+\Delta)}{(1-d)(1-\alpha)+\alpha}, r_1\right]$</td></tr>
<tr><td>IC-IC: $\begin{cases} p_n^{(IC-IC)} = \Delta + rd(1-\alpha) \\ p_o^{(IC-IC)} = (1-\beta)\Delta + rd(1-2\alpha) \end{cases}$</td></tr>
<tr><td>P-P: $\begin{cases} p_n^{(P-P)} = v + \Delta - r(1-d)(1-\alpha) \\ p_o^{(P-P)} = \beta v + r(1-d)\alpha \end{cases}$</td></tr>
<tr><td>P-IC:
$\begin{cases} p_n^{(P-IC)} = v + \Delta - r(1-d)(1-\alpha) \\ p_o^{(P-IC)} = v + (1-\beta)\Delta - r[(1-d)(1-\alpha) + d\alpha] \end{cases}$</td></tr>
</table>

Proposition 1 below summarizes the impact of the reference-group effect on profits.

Proposition 1 (Impacts of the Reference-Group Effect on Profits)

Under the Sequential-Adoption strategy,

(a) The firm earns a higher profit when the product is subject to the reference-group effect than when it is not, as long as this effect is not too strong.

(b) For products subject to the reference-group effect, the firm's profit first increases and then decreases with it.

Formally,

(a) $\pi^*(r) > \pi^*(r = 0)$ *iff* $r \in (0, \hat{r}]$.

(b) $\frac{\partial \pi^*}{\partial r}\begin{cases} > 0 & \text{for } r \leq r_1 \\ = 0 & \text{for } r \in (r_1, r_2]. \\ < 0 & \text{for } r > r_2 \end{cases}$

We graphically illustrate Proposition 1 in Figure 1. First, it is interesting to find that the existence of the reference-group effect can benefit the firm (i.e., profit for $r \in (0, \hat{r}]$ is higher than profit for $r = 0$). This finding underscores the fact that, as advances in technology make high-tech products more portable/wearable (e.g., cell phones, laptops, and cameras) and thus create reference-group effects and social utility, the firm can benefit more from new product introduction. However, the firm's profit decreases when the reference-group effect is too strong (i.e., $r > \hat{r}$).

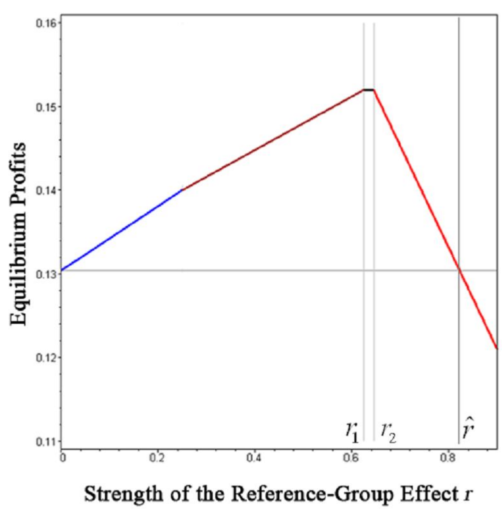

Figure 1. Optimal Equilibrium Profits as a Function of the Reference-Group Effect r

Second, as shown in Figure 1, the reference-group effect has a nonlinear impact on the firm's profit. Specifically, the reference-group effect r affects the optimal profit differently in three parameter ranges, first positively (*IC-P* and/or *IC-IC*)[8], then no impact (*P-P*), and finally negatively (*P-IC*). These findings demonstrate that, when products offer both functional and social utility to consumers, the reference-group effect plays a crucial role in determining the firm's pricing schemes and thus its profit.

This unique nonlinear impact of the reference-group effect on profit is driven by its opposite impacts on leaders' and followers' social (dis)utility, as well as by potential cross-version competition between the original and new versions. The negative reference-group effect on leaders' utility implies that followers' adoption of the original version can make the latter less attractive to leaders, thus "pushing" leaders to upgrade to the new version. This *push* effect consequently increases the firm's profit under the *Sequential-Adoption* strategy. On the other hand, the positive reference-group effect on followers' utility implies that leaders' adoption of the new version can make the latter more attractive to followers, thus "pulling" followers away from the original version. This *pull* effect consequently decreases the firm's profit under the *Sequential-Adoption* strategy. Fundamentally, the *push* and *pull* effects are driven by cross-version competition for the respective segments. We elaborate below how the *push* and *pull* effects work in three parameter ranges of the reference-group effect and lead to this non-linear impact on profits.

Case 1: A Weak Reference-Group Effect ($r \leq r_1$). This is a parameter range where cross-version competition exists for leaders and the *push* effect arises. This *push* effect makes the optimal profit increase with r (although this positive effect differs in its magnitude depending on whether or not the *pull* effect also exists). In this range, two possible pricing schemes may be optimal: *IC-P* and *IC-IC*.

First, for leaders, a small r implies a low disutility due to followers' adoption. As a result, leaders can still enjoy a positive utility by staying with the original version after followers adopt it. Hence, cross-version competition exists for leaders. A larger r "pushes" leaders to pay more for the new version because it intensifies leaders' negative social utility caused by followers' adoption. Such a negative social utility is stronger if leaders share the same original version with followers than if they adopt a differientiated new version (see leaders' utility function (8)). This suggests that, as r increases, the original version becomes less attractive and the incremental value of the new version to leaders increases. As a result, a larger reference-group effect increases leaders' willingness-to-pay for

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[8]Under both schemes, profit increases with r, but the two slopes differ, as indicated in Proposition 1, depending on the product characteristics (d and Δ). We present this in greater detail in the proof to Lemma 1 in Appendix.

the new version, and thus increases its optimal price.

For followers, cross-version competition may or may not occur in this weak range of r.[9] No matter whether the *pull* effect exists or not, the overall impact of r is always positive. When the *pull* effect exists (i.e., the optimal pricing is *IC-IC*), an increase in r can mitigate its negative impact and allow the firm to charge a higher price for the original version. This is because the optimal price of the original version is set such that followers will be indifferent between adopting the new or the original version. As the optimal price of new version increases with r, that of the original version also rises.[10] When the *pull* effect is absent (i.e., the optimal pricing is *IC-P*), a larger r can also increase the optimal price of the original version, but for a different reason. In the absence of cross-version competition for followers, the optimal price of the original version is determined by followers' utility from the latter, which is positively impacted by the reference-group effect (see followers' utility function (10)).

Since, as elaborated above, a larger r leads to a higher price for both products, the reference-group effect positively impacts optimal profit when the former is weak.

Case 2: An Intermediate Reference-Group Effect ($r \in (r_1, r_2]$). As r increases and reaches r_1, the optimal pricing scheme switches to *P-P*, i.e., no cross-version competition exists for either segment. This situation occurs because, as r becomes sufficiently strong ($r > r_1$), leaders' social disutility from using the original version is too high such that the original version does not offer them a positive utility. On the other hand, the optimal price of the new version has increased to such a level that it is no longer attractive to followers. Hence, the optimal price of each product is determined by the utility of the targeted segment only. Since r generates a disutility for leaders but a positive utility for followers (see the utility functions (8) and (10)), a larger r decreases the optimal price of the new version and increases the price of the original. These two opposite effects on the optimal profit cancel each other out. As a result, the reference-group effect does not affect the profit in this parameter range.

Case 3: A Strong Reference-Group Effect ($r > r_2$). As r further increases and reaches r_2, the

[9]Two opposite forces determine when the *pull* effect arises in this range of r. We discuss this in the proof to Lemma 1 in Appendix.

[10]A larger r may also make the new version more attractive to followers, since the latter gain higher social utility by using the same version as leaders, which may make the impact of r on p_o negative. As shown in Lemma 1, this happens when there are more leaders than followers in the market, i.e., $\alpha > 1/2$, which is a rare case. The overall impact of r on profits is always positive, however, regardless of the leaders' segment size.

optimal pricing policy switches from *P-P* to *P-IC*, i.e., cross-version competition emerges again for followers. This situation occurs because, as r becomes very strong ($r > r_2$), followers'social utility from using the same version as leaders is strong enough for the new version to become attractive and hence compete with the original product. In this case, an increase in r decreases profits since it forces the firm to lower prices for both products. First, the optimal price of the new version is determined by leaders' utility from the new version since no cross-version competition exists for leaders. A larger r reduces leaders' utility from the new version and hence reduces its optimal price. Second, a larger r reinforces the negative *pull* effect and reduces the optimal price for the original version. This occurs because, in the presence of cross-version competition for followers, the optimal price of the original version is set at a level whereby followers will not be worse off by adopting it. The lower price of the new version caused by a larger r leads to a lower price for the original.

In sum, when the reference-group effect is weak, the *push* effect, stemming from cross-version competition for leaders, leads to a positive impact on profits; otherwise, a strong reference-group effect reduces profits due to the *pull* effect, stemming from cross-version competition for followers. Therefore, the firm benefits from the reference-group effect as long as it is not too strong, but suffers from it when it is very strong.

Proposition 1 demonstrates how the reference-group effect impacts profits when the firm introduces a new product to the market. However, due to the product development cost, new product introduction may not always be profitable, i.e., the firm may earn a higher profit by not launching the new product but selling the original product only in both periods. It is interesting to ask how the reference-group effect may impact the firm's incentive for introducing a new product. To answer this question, we compare the firm's profit under the *Sequential-Adoption* strategy with profit under the *No-New-Product* strategy (i.e., the original product is the only offering in both periods). We summarize our results in Corollary 1.

Corollary 1 (Impacts of the Reference-Group Effect on New Product Introduction)

Changes in the reference-group effect impact firm's incentive to introduce a new product. Specifically, increased reference-group effects may turn new product introduction from an unprofitable to a profitable strategy. However, in markets with extremely strong reference-group effects, further increase of such an effect may turn new product introduction from a profitable to an unprofitable strategy.

Formally,

$$\pi^*(Sequential\ Adoption) \geq \pi^*(No\ New\ Product)\ \ iff\ \ r \in (\underline{r}^{new}, \bar{r}^{new}].$$

In technology product markets, high product development costs often discourage product innovation. Interestingly, Corollary 1 reveals that as the reference-group effect becomes stronger for some technology products (e.g., due to technology advances in product portability/wearability), firms may be more willing to develop and introduce new products. Such a positive impact of the reference-group effect on innovation is driven by the positive "push" effect discussed earlier, which occurs only when a new product is available to leaders and allows them to avoid sharing the same product with followers. As a result, an increase in the strength of the reference-group effect can facilitate innovation. However, the existence of a new product also creates a negative "pull" effect, which reduces the profitability of new product introduction in markets with very strong reference-group effects. Hence, too strong reference-group effects may discourage innovation.

Product characteristics can mitigate the cross-version competition effects. We therefore turn our attention to the impact of the charactersitics of the new version on pricing schemes and profits. Specifically, Proposition 2 below shows how product differentiation between the two versions along two dimensions, the exterior differentiation d and the incremental functionality Δ, impact profits. These findings will provide insights into how the firm should optimally design the new version by leveraging the cross-version competition effects (see Section 4).

Proposition 2 (Impacts of Product Differentiation on Profits)

Under the Sequential-Adoption strategy, profit weakly increases with the level of product differentiation, as measured by the exterior difference d, and the incremental functionality Δ. The existence and the magnitude of these impacts depend on the strength of the reference-group effect. Specifically,

(a) A larger d improves profits in the presence of cross-version competition for followers, but has no impact on profits in its absence.

(b) A larger Δ always improves profits, and such a positive impact is stronger in the presence of cross-version competition for followers than in its absence.

Formally,

$$\frac{\partial \pi^*}{\partial d}\begin{cases} > 0 & \text{for } r \in \Gamma \\ = 0 & \text{otherwise} \end{cases}, \text{ and}$$

$$\left.\frac{\partial \pi^*}{\partial \Delta}\right|_{r \in \Gamma} > \left.\frac{\partial \pi^*}{\partial \Delta}\right|_{r \notin \Gamma} > 0,$$

where Γ is a set of r in which the optimal pricing scheme is either IC-IC or P-IC (i.e., cross-version competition occurs for followers).

Proposition 2(a) reveals that, when there is cross-version competition for followers (i.e., when r

is small or large as discussed in Proposition 1),[11] a larger exterior difference, d, between the two versions increases profits. This is because a larger d helps leaders suffer less from social disutility and hence increases the optimal price of the new version. In the presence of cross-version competition for followers, an increase in the optimal price of the new version leads also to an increase in the optimal price of the original. However, exterior differentiation does not affect profit when cross-version competition is absent for followers. A larger d increases leaders' willingness-to-pay for the new version, but decreases followers' willingness-to-pay for the original, and the two opposite impacts cancel each other out.

Proposition 2(b) reveals that a higher Δ increases the firm's profits in all possible pricing schemes because it increases the incremental value of the new version to leaders and, hence, increases its optimal price. This positive impact is stronger, however, when cross-version competition exists for followers. This occurs because, in the presence of cross-version competition for followers, the optimal price of the original is dependent on the optimal price of the new version. Hence, an increase in the price of the new version, due to a larger Δ, also leads to an increase in the price of the original.

Recall that we point out, in the discussion of Proposition 1, that cross-version competition for followers creates a *pull* effect and, when it is strong enough, it decreases the firm's profits with the reference-group effect. The findings in Proposition 2 offers an important insight: When such a negative *pull* effect is present, the exterior differentiation (d) and the incremental functionality (Δ) of the new version can serve as strategic tools for the firm to soften the negative impact (i.e., by mitigating the competition effect) and hence enhance profits. However, a high differentiation level in either dimension (i.e., very dissimilar exterior design or a significantly enhanced functionality) implies a high development cost. In the next section, we examine how the firm can optimally design the new version in order to maximize profit.

3.2. The Optimal Design Policy

In this section, we derive the optimal level of the exterior differentiation (d^*) and incremental functionality (Δ^*) of the new version in the presence of the reference-group effect. We first present d^* and Δ^* in Lemma 2, and then summarize our major insights in Propositions 3 and 4.

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[11]We present in the proof to Lemma 1 in Appendix the detailed conditions of r under which either *IC-IC* or *P-IC* arises.

Lemma 2 (The Optimal Product Design)

The optimal design of the new version is given in the table below:

Parameter Range		***Optimal Exterior Differentiation*** (d^*)	***Optimal Incremental Functionality*** (Δ^*)
(1) $r \le \underline{r}$		$d^* = 0$	$\Delta^* = \frac{\delta\alpha(1-c)}{2k_1}$ $\frac{\partial\Delta^*}{\partial r} = 0, \frac{\partial\Delta^*}{\partial v} = 0$
(2) $r \in (\underline{r}, \bar{r}]$	(a) $v > r(1-\alpha)$	$d^* = d^{(a)}$ $\frac{\partial d^*}{\partial r} > 0, \frac{\partial d^*}{\partial v} < 0$	$\Delta^* = \Delta^{(a)}$ $\frac{\partial\Delta^*}{\partial r} > 0, \frac{\partial\Delta^*}{\partial v} < 0$
	(b) $v \le r(1-\alpha)$	$d^* = d^{(b)}$ $\frac{\partial d^*}{\partial r} > 0, \frac{\partial d^*}{\partial v} > 0$	$\Delta^* = \Delta^{(b)}$ $\frac{\partial\Delta^*}{\partial r} > 0, \frac{\partial\Delta^*}{\partial v} > 0$
(3) $r > \bar{r}$		$d^* = \frac{\delta r(1-\alpha)^2}{2k_2}$ $\frac{\partial d^*}{\partial r} > 0, \frac{\partial d^*}{\partial v} = 0$	$\Delta^* = \frac{\delta[(1-\beta) + \alpha(\beta - c)]}{2k_1}$ $\frac{\partial\Delta^*}{\partial r} = 0, \frac{\partial\Delta^*}{\partial v} = 0$

where, $d^{(a)} = \frac{r(1-\alpha)[2k_1(r\alpha+\beta v)-\alpha\delta(1-\beta)(1-c)]}{2[k_1r^2(1-\alpha)^2+k_2(1-\beta)^2]}, \Delta^{(a)} = \frac{\beta v - r[(1-\alpha)d^{(a)}-\alpha]}{1-\beta},$

$$d^{(b)} = \frac{r(1-\alpha)[2k_1(r - v + \beta v) - \alpha\delta(1-\beta)(1-c)]}{2[k_1r^2(1-\alpha)^2 + k_2(1-\beta)^2]}, \Delta^{(b)} = \frac{r[(1-\alpha)(1-d^{(b)}) + \alpha]}{1-\beta} - v,$$

and expressions for $\underline{r}$ *and* $\bar{r}$ *are presented in Proposition A2 in the online supplement.*

Proposition 3 (The Optimal Product Design)

The optimal design of the new version in both the functional (Δ^*) *and the exterior* (d^*) *dimensions depends on the strength of the reference-group effect (r) and the base functional value* (v)*. As shown in the table below, depending on the value of* r*, there are three optimal design policies, (1) Functional-Only Differentiation, (2) Joint Differentiation, and (3) Exterior-Focused Differentiation. The required condition for each policy to be optimal is affected by the value of* v*.*

Optimal Design	***Description***	***Condition***
Functional-Only Differentiation	• *The two versions differ only in functional value;* • Δ^* *is independent of* r*.*	$r \le \underline{r}$
Joint Differentiation	• *The two versions differ in both dimensions;* • *A larger r increases differentiation in* d^* *and* Δ^**.*	$r \in (\underline{r}, \bar{r}]$
Exterior-Focused Differentiation	• *The two versions differ in both dimensions;* • *A larger r increases differentiation in* d^* *only.*	$r > \bar{r}$
where, $\frac{\partial\underline{r}(v)}{\partial v}, \frac{\partial\bar{r}(v)}{\partial v} > 0$ *for* $v \le r(1-\alpha)$*;* $\frac{\partial\underline{r}(v)}{\partial v}, \frac{\partial\bar{r}(v)}{\partial v} < 0$ *for* $v > r(1-\alpha)$*.*		

Proposition 3 discusses how the reference-group effect (r) and the base functional value (v) impact the optimal exterior differentiation d^* and functional differentiation Δ^*.

Figure 2 graphically presents the conditions, given in Proposition 3, under which each of the three design policies dominates others. As shown in Figure 2, these conditions are jointly determined by r and v. First, as r increases, the firm's optimal design policy switches from *Functional-Only Differentiation* to *Joint Differentiation*, and finally to *Exterior-Focused Differentiation*. Second, the relative attractiveness of each optimal design policy is affected by v (i.e., the boundaries of the three optimal design regions, $\underline{r}$ and $\bar{r}$, are function of v). We discuss the economic intuitions behind the impacts of these two factors, r and v, on the optimal design below.

Impact of the Reference-Group Effect on Optimal Design. The optimal design policy pattern shown in Figure 2 suggests that, as r increases, the firm changes its strategic focus on the two design dimensions, d^* and Δ^*, as follows: first on the functional dimension, then on both dimensions, and finally on the exterior dimension. As we explain below, this strategic shift allows the firm to use the most effective type of product differentiation to avoid/weaken cross-version competition and maximize profits.

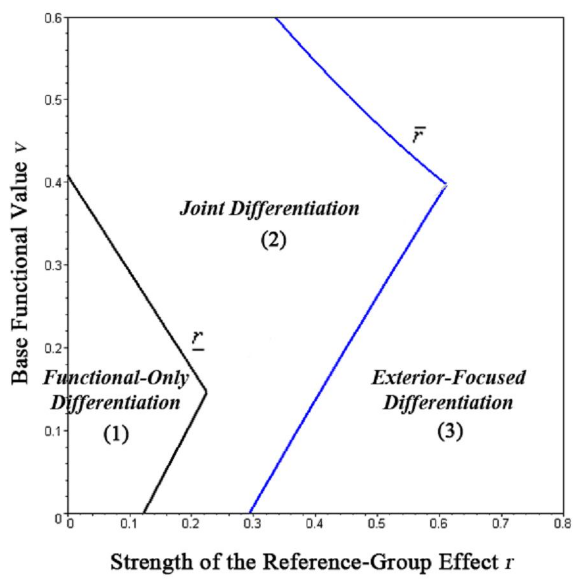

Figure 2. Three Optimal Product Design Policies

When the reference-group effect r is weak ($r \leq \underline{r}$), the optimal design policy is *Functional-Only Differentiation*, i.e., introducing a new version with a higher functionality without necessarily changing the exterior appearance (i.e., $\Delta^* > 0$, $d^* = 0$) because, in this region, the social value plays a weak role in consumers' valuation due to a small r. No cross-version competition exists for followers (i.e., the *pull* effect does not arise via *P-P* or *IC-P* pricing scheme) and the firm does not need to soften the competition by differentiating the exterior of the new version. However, the firm is able to improve its profit by increasing the functionality of the new version and hence enhance its attractivessness to leaders. In the absence of the *pull* effect, the optimal incremental functionality Δ^* is simply determined by the tradeoff between leaders' functional appreciation and the firm's development cost, and thus is independent of r for $r \leq \underline{r}$. Both d^* and Δ^* are the lowest in this region.

As r becomes stronger and reaches $\underline{r}$, the optimal design policy changes to *Joint Differentiation*: differentiating the new version from the original in both dimensions. As the social value becomes sufficiently important due to a larger r, it is too costly for the firm to eliminate cross-version competition through enhanced functionality alone, but finds it more efficient to design the differentiation levels of both dimensions jointly. Under the *Joint-Differentiation* policy, the firm coordinates the optimal levels of d^* and Δ^* to ensure that the new version does not offer a positive surplus to followers (i.e., both *P* and *IC* constraints are binding for followers, and thus the *pull* effect can be avoided).[12] The firm is able to do so only up to a certain level of the reference-group effect ($\overline{r}$). In the region, $r \in (\underline{r}, \overline{r}]$, an increase in r increases the attractiveness of the new version to followers. Hence, to avoid cross-version competition for followers, the optimal differentiation levels in both dimensions must be higher as r increases (i.e., $\frac{\partial \Delta^*}{\partial r}, \frac{\partial d^*}{\partial r} > 0$). In this region, both d^* and Δ^* are intermediate.

When r becomes very strong ($r > \overline{r}$), the optimal design policy shifts to *Exterior-Focused Differentiation*, under which the firm offers a maximum, constant functional differentiation Δ^*, and focuses on the exterior differentiation d^* only. This occurs because the attractiveness of the new version to followers becomes so strong that it is not economical to continue increasing the differentiation in both design dimensions in order to completely avoid cross-version competition for followers. Rather, it is more advantageous for the firm to allow the *pull* effect via implementing

[12] We present greater detail about which *P* and/or *IC* constraints are binding for each segment in each region in Proposition A2 in the online supplement.

pricing schemes *IC-IC* or *P-IC*. As r increases, the firm will maintain the same level of Δ^* while increasing d^* in order to weaken cross-version competition and reduce the negative *pull* effect.[13] In this region, both exterior and functional differentiation are the largest, but the former plays a major role in reducing the negative *pull* effect as r increases.

Impact of Base Functional Value on Optimal Design. As shown in Figure 2, the two boundary conditions, $\underline{r}$ and $\overline{r}$, divide the design space into three regions. Within each region, one unique design policy dominates others. Interestingly, both $\underline{r}$ and $\overline{r}$ first increase but then decrease with the base functional value, v. Recall that the firm chooses the most effective design policy to avoid/weaken cross-version competition and thus maximize profits. The nonlinear impact of v shown in Figure 2 suggests that v affects the relative effectiveness of each design policy by its role in managing cross-version competition.

We first discuss the impact of v on $\overline{r}$, which determines the relative advantage of two design policies, *Joint Differentiation* (when $\underline{r} < r < \overline{r}$) and *Exterior-Focused Differentiation* (when $r > \overline{r}$). As pointed out earlier (see the discussion on the impact of r on the optimal design), under the *Joint-Differentiation* policy, the firm is able to eliminate cross-version competition for followers. However, under the *Exterior-Focused-Differentiation* policy, because of a large r, it is too costly to fully remove cross-version competition for followers, and thus the firm can only mitigate it, suggesting that an increase in v will favor *Joint Differentiation* if it weakens cross-version competition for followers (i.e., by making the new version less attractive to them). This scenario holds when v is sufficiently low (i.e., $v \le r(1-\alpha)$) that the original version fails to offer a positive value to leaders (given its social disutility to them). In other words, no cross-version competition exists for leaders, and the optimal price of the new version is determined by its value (rather than the incremental value) to them. Thus, the optimal price of the new version increases as v increases. As a result, a larger v makes it more cost-effective for the firm to eliminate cross-version competition for followers by using *Joint Differentiation*, i.e., $\overline{r}$ is increasing in v.

However, such a positive effect of v on $\overline{r}$ disappears when v becomes sufficiently high (i.e., $v > r(1-\alpha)$), such that the original version offers a positive utility to leaders. In other words,

[13]As suggested in Proposition 2, a larger exterior differentiation (d) increases the firm's optimal profits in regions where cross-version competition exists for followers. Figure A1 in the online supplement shows how the optimal designs change with r. Figure A3 shows how the optimal prices and profit change with r.

cross-version competition exists for leaders. So, the optimal price of the new version is only determined by its incremental value Δ, which is independent of v. Hence, an increase in v makes the new version more attractive to followers, because it raises its functional value without raising its price, which increases cross-version competition pressure for followers. Hence, a larger v makes it more costly for the firm to eliminate cross-version competition for followers by using *Joint Differentiation*, but instead favors *Exterior-Focused Differentiation*, i.e., $\overline{r}$ is decreasing in v.

Next, we consider the impact of v on $\underline{r}$, which follows the same logic as for the impact of v on $\overline{r}$. The condition $\underline{r}$ determines the relative advantage of two design policies, *Functional-Only Differentiation* ($r < \underline{r}$) and *Joint Differentiation* ($r > \underline{r}$). As stated earlier (see the discussion on the impact of *r*), cross-version competition for followers is absent under the former policy, but is barely eliminated under the latter policy, which suggests that an increase in v will favor *Functional-Only Differentiation* if it weakens cross-version competition for followers but otherwise will favor *Joint Differentiation.* When v is low (i.e., $v \leq r(1-\alpha)$), no cross-version competition exists for leaders. When v increases, the higher price of the new version reduces the cross-version competition pressure for followers, and hence a larger v favors the *Functional-Only-Differentiation* policy, i.e., $\underline{r}$ is increasing in v. When v is sufficiently large (i.e., $v > r(1-\alpha)$), cross-version competition for leaders limits the price of the new version. An increase in v intensifies cross-version competition for followers and favors the *Joint-Differentiation* policy, i.e., $\underline{r}$ is decreasing in v.[14]

In sum, the above discussion underscores the fact that, when introducing a new version, it is important for the firm to design the new version strategically based on the strength of the reference-group effect and the level of the base functional value of the product.

4. Optimal Product Targeting Strategy

In the previous sections, we have focused on one commonly observed strategy, *Sequential Adoption*, under which the new version is designed and priced to target leaders only. The firm can also consider two alternative targeting strategies: 1) design and price the new version to attract both segments (i.e., the *Simultaneous-Adoption* strategy) or 2) attract followers only (i.e., the *Leap-Frog-Adoption* strategy). In this section, we examine the firm's optimal targeting strategy. We first derive the

[14]We discuss in greater detail in the online supplement how Δ^* and d^* first (weakly) decrease then (weakly) increase in v, and achieve the lowest at an intermediate value of v (see Figure A2 and Proposition A2).

equilibrium pricing and optimal design policies for the two alternative targeting strategies (presented in Propositions A1 and A2, respectively, in the online supplement), and then derive the conditions under which each of the three targeting strategies, *Sequential Adoption*, *Simultaneous Adoption*, and *Leap-Frog Adoption*, dominates the others. Propostion 4 summarizes our main findings.

Proposition 4 (Optimal Targeting Strategy)

When introducing an updated new version, the firm can maximize profit by strategically selecting the targeted segment of its innovation (via its optimal design and pricing) based on the strength of the reference-group effect (r) and the base functional value (v), as summarized in the table below:

Optimal Targeting Strategy	***Targeted Segment(s) of the New Version***	***Reference-Group Effect (r)***	***Base Function (v)***
Sequential Adoption	*Leaders only*	*Weak or Strong*	*Sufficiently Low*
Simultaneous Adoption	*Both segments*	*Intermediate*	
Leap-Frog Adoption	*Followers only*		*Sufficiently High*

Proposition 4 reveals how the optimal targeting strategy is impacted by the technological and social characteristics of the product. First, the base functional value v determines whether or not the firm should design and price the new version to target leaders: It is optimal to make the new version attractive to leaders (via *Sequential Adoption* or *Simultaneous Adoption*) if v is low; but target followers only (via *Leap-Frog Adoption*) if v is high. Unlike followers, leaders already own the original version at the time of introduction of the new version and can continue using the technology product without additional cost. To induce leaders to upgrade (and pay for the new version), the new version has to offer a sufficient incremental value. However, it is expensive to futher enhance technological functionality when v is already very high. As a result, when v is high, it is not cost-efficent for the firm to design the new version to target the leaders. Rather, it is more profitable to introduce a new version without substantial functional advancement to target followers (via *Leap-Frog Adoption*), who are positively impacted by its social utility.

Second, when v is low, it is profitable to motivate leaders to adopt the new version. However, the value of r determines whether or not it is optimal to target the new version to leaders exclusively or to both segments: leader only (*Sequential Adoption*) if r is weak or strong, but both segments (*Simultaneous Adoption*), otherwise. When v is relatively low, it becomes easier for the firm to offer some incremental functional value in the new version in order to make it attractive to leaders. In addition, as social value now plays an important role, the firm could leverage either the reference-group's *push* effect on leaders by making followers adopt the original version, i.e., *Sequential Adoption*, or the reference group's stimulating effect on followers by making the latter adopt the same version as leaders, i.e., *Simultaneous Adoption*. We find that *Sequential Adoption* dominates *Simultaneous Adoption* at either low or high values of r. Recall that, at low values of r, the reference-group effect plays a positive role in both leaders' and followers' willingness-to-pay in *Sequential Adoption*, as discussed in Proposition 1 in Section 3.1. However, in *Simultaneous Adoption*, the reference-group effect plays a positive role only in followers' willingness-to-pay. Thus *Sequential Adoption* is preferred at low values of r. At high values of r, the reference-group effect plays a negative role in leaders' willingness-to-pay in both strategies, but this is stronger in *Simultaneous Adoption* because the two segments are using the same version. Thus *Sequential Adoption* is preferred at high values of r.[15]

5. Concluding Remarks

In today's markets, as advances in technology continue increasing product portability/wearability, many traditional consumer technology products can satisfy consumers' social needs, in terms of distinction and assimilation, in addition to providing functional utility. Driven by this emerging market phenomenon, this research investigates the impact of the reference-group effect on firms' innovation decisions. Our results illustrate that, when introducing an enhanced version of an existing product, the firm should carefully assess not only the functional value, but also the potential social value of the product to its buyers. If owning the product creates social (dis)utility, a consumer's adoption decision can be determined not only by the product itself (i.e., its basic functional value), but also by the purchase behavior of other consumer segments with different social statuses. To maximize profits in such markets, the firm should develop a good understanding of how the reference-group effect may impact the willingness-to-pay of different consumer segments, and strategically leverage

[15]The firm has an option of not to introduce a new version. However, this strategy is always dominated by the *Leap-Frog-Adoption* strategy, whereby the firm could leverage the same level of reference-group effect by inducing followers to adopt a new version with zero exterior differentiation, but is able to gain higher profits due to the new version's higher functional value. There are two other possible strategies when the firm introduces a new version: 1) Leaders dispose of the original version and followers adopt the new version; and 2) leaders adopt the new version and followers do not purchase either version. It can be shown that they are dominated by the *Sequential-Adoption* and *Leap-Frog-Adoption* strategies, respectively.

such cross-segment effects in its product pricing scheme, new product design policy, and targeting strategy.

Our research findings lead to the following specific managerial implications: First, we find that the relatively newly acquired social function of technology products can significantly affect the profitability of new product introduction. For example, when introducing a new product version, many firms implement the *Sequential-Adoption* strategy, under which firms set prices to induce existing users (leaders) to upgrade to the new version and new users (followers) to adopt the original version. In this case, the reference-group effect can create a positive cross-segment *push* effect: Followers' adoption of the original product motivates leaders to upgrade (due to leaders' social disutility from sharing the same version with followers). However, the reference-group effect can also create a negative cross-segment *pull* effect: Leaders' adoption of the new version reduces the attractiveness of the original version to followers (due to the latter's social utility from sharing the same version with leaders). Firms should take such cross-version competition effects into account in their pricing decisions and strategically leverage the positive *push* and minimize the negative *pull* effects in order to maximize profits.

Second, firms should also strategically utilize the reference-group effect in their product design policy, i.e., how to determine product differentiation between the new and existing versions in two design dimensions: functionality and exterior appearance. Specifically, as the reference-group effect increases, it is more profitable to shift the differentiation focus from functionality to exterior appearance. In markets with a weak reference-group effect, it does not benefit the firm to differentiate exterior appearance (i.e., *Functional-Only Differentiation* is optimal); in markets with a very strong reference-group effect, the firm can significantly increase profits by raising the differentiation level in exterior appearance, but not in functionality, as the reference-group effect becomes stronger (i.e., *Exterior-Focused Differentiation* is optimal); only in markets with an intermediate reference-group effect can the firm maximize its profit by jointly differentiating both functionality and exterior design (i.e., *Joint Differentiation* is optimal).

Third, firms can strategically exploit the reference-group effect by targeting its new product to the most profitable segment(s), i.e., to leaders only (*Sequential Adoption*), to both leaders and followers (*Simultaneous Adoption*), or followers only (*Leap-Frog Adoption*). In the presence of the reference-group effect, it is more profitable for firms to design and price the new version to motivate their existing users (leaders) to upgrade when consumers are using the product to fulfill certain social needs, such as signaling their social status and lifestyle, rather than for its functionality and, otherwise, firms should focus on promoting the new version to newly arriving consumers (followers).

Our research has some limitations, but these also lead to future research opportunities. In the study, we assumed that only the exterior form has social value. In some cases, different exterior forms may have different aesthetic values (Bloch 1995, Kreuzbauer and Malter 2005, Schmitt and Simonson 1997, Wagner 1999). On the other hand, functional features may also play a role in communicating symbolic meanings. Furthermore, exterior form may also communicate functional characteristics to the consumer (Creusen and Schoormans 2005). Future research could extend the model by examining these joint effects in firms' product design strategies.

Our paper considers a monopoly firm optimizing its product strategies. It would be interesting to extend the analysis to a competitive situation, in which firms must also take into account their competitors' strategic moves when developing optimal design and pricing strategies. In addition, we focus on the reference-group effect at the product or brand level, which is determined by the visibility and portability of the product and, hence, we make the assumption that the strength of the reference-group effects is the same for both leaders and followers. Future research can relax this assumption by examining consumer-specific reference-group effects. Most importantly, another avenue for future research is to test our predictions empirically.

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Appendix: Proofs

Proof of Lemma 1:

The four constraints, equations (12)-(16), in Section 3.1, can be rewritten as,

$$\begin{cases} p_{o,1} \le v & (12) \\ p_n \le v + \Delta - r(1-d)(1-\alpha) & (13) \\ p_n \le \Delta + rd(1-\alpha) & (14) \\ p_o \le \beta v + r(1-d)\alpha & (15) \\ p_n \ge p_o + \beta\Delta + rd\alpha & (16) \end{cases}$$

The first constraint (12) is always binding, i.e., $p_{o,1}^* = v$. It is easy to check whether the other constraints (13)-(16) are binding or not depends on the following conditions:

Binding Constraints	$d < \alpha/(1-\alpha)$	$d \ge \alpha/(1-\alpha)$
$\Delta \le \beta v/(1-\beta)$	$\begin{cases} (IC-IC) & \text{for } r \le r_1 \\ (P-IC) & \text{for } r > r_1 \end{cases}$	$\begin{cases} (IC-IC) & \text{for } r \le r' \\ (IC-P) & \text{for } r \in (r', r_1] \\ (P-P) & \text{for } r \in (r_1, r_2] \\ (P-IC) & \text{for } r > r_2 \end{cases}$
$\Delta > \beta v/(1-\beta)$	$\begin{cases} (IC-P) & \text{for } r \le r' \\ (IC-IC) & \text{for } r \in (r', r_1] \\ (P-IC) & \text{for } r > r_1 \end{cases}$	$\begin{cases} (IC-P) & \text{for } r \le r_1 \\ (P-P) & \text{for } r \in (r_1, r_2] \\ (P-IC) & \text{for } r > r_2 \end{cases}$

where the first (IC) or (P) indicates whether leaders' constraint (13) or (14) is binding, and the second (IC) or (P) indicates whether followers' constraint (15) or (16) is binding, and

$$r' = \frac{\beta(v+\Delta)-\Delta}{d(1-\alpha)-\alpha},\ r_1 = \frac{v}{1-\alpha},\ r_2 = \frac{(1-\beta)(v+\Delta)}{(1-d)(1-\alpha)+\alpha}.$$

The binding constraints in each case lead to the optimal prices p_n and p_o summarized in Lemma 1.

Depending on the values of exterior differentiation *d* and base functional value Δ, not necessarily all pricing schemes will emerge. However, the role of the reference-group effect remains the same as in Figure 1, i.e., the optimal profit first incerases then decreases in *r*. As a footnote to Proposition 1 in Section 3.1, two opposite forces determine when the *pull* effect arises in the weak range of *r* ($r \le \hat{r}$). Due to cross-version competition for leaders, to motivate leaders to adopt the new version, the price of the new version has to be sufficiently low. The low price of the new version implies a strong attractiveness of the new version to followers. On the other hand, a small *r* implies that they gain low social utility if adopting the same version as leaders, and hence a small *r* implies a weak attractiveness of the new version to followers. When the first effect dominates the second, the *pull* effect arises; otherwise, not.

Proof of Proposition 1:

The optimal profits π^* in each pricing scheme are given by

$$\pi^{(IC-IC)} = \alpha v + \delta[\alpha + (1-\alpha)(1-\beta)]\Delta + r\delta(1-\alpha)^2 d - C$$
$$\pi^{(IC-P)} = [\alpha + (1-\alpha)\beta\delta]v + \delta\alpha\Delta + r\delta\alpha(1-\alpha) - C$$
$$\pi^{(P-P)} = [\alpha + \delta\alpha + \delta(1-\alpha)\beta]v + \delta\alpha\Delta - C$$
$$\pi^{(P-IC)} = (\alpha + \delta)v + \delta[\alpha + (1-\alpha)(1-\beta)]\Delta - r\delta(1-\alpha)[1-(1-\alpha)d] - C$$

It is easy to check that $\frac{\partial \pi^{(IC-IC)}}{\partial r} > 0$, $\frac{\partial \pi^{(IC-P)}}{\partial r} > 0$, $\frac{\partial \pi^{(P-P)}}{\partial r} = 0$, and $\frac{\partial \pi^{(P-IC)}}{\partial r} < 0$.

Because as *r* increases, (IC-IC) and/or (IC-P) emerges first, followed by (P-P), and finally (P-IC), there exists a critical $\hat{r}$, such that $\pi^*(r) > \pi^*(r=0)$ iff $r \le \hat{r}$.

Proof of Corollary 1:

In the following, we first derive the equilibrium when the firm does not introduce a new version in the 2nd period. Leaders' WTP for the product depends on their choices in the second period: Either keep using it or dispose of it. Followers' utility also depends on leaders' choice. We have the following three possible cases:

(1) Leaders keep the original product and followers adopt it with utilities:

$U_l = v + \delta[v - r(1-\alpha)] - p_{o,1}$ and $U_f = \delta(\beta v + r\alpha - p_o)$.

This case arises in equilibrium when $\begin{cases} (1): U_l \ge 0 \Rightarrow p_{o,1} \le (1+\delta)v - \delta r(1-\alpha) \\ (2): U_f \ge 0 \Rightarrow p_o \le \beta v + r\alpha \\ (3): U_l(I) \ge v - p_{o,1} \Rightarrow v \ge r(1-\alpha) \end{cases}$.

Hence, when $v > (1-\alpha)r$, or $r \le \frac{v}{1-\alpha}$, a solution exists

$$\begin{cases} p_{o,1}{}^{*} = (1+\delta)v - \delta r(1-\alpha) \\ p_o{}^{*} = \beta v + r\alpha \\ \pi^{*} = [\alpha(1+\delta)+\delta(1-\alpha)\beta]v - [\alpha+(1-\alpha)\delta]vc \end{cases}$$, where (1) and (2) are binding.

(2) Leaders dispose and followers adopt the original version with utilities:

$U_l = v - p_{o,1}$ and $U_f = \delta(\beta v - p_o)$.

This case arises in equilibrium when $\begin{cases} (1): U_l \geq 0 \Rightarrow p_{o,1} \leq v \\ (2): U_f \geq 0 \Rightarrow p_o \leq \beta v \\ (3): U_l \geq v + \delta[v - r(1-\alpha)] - p_{o,1} \Rightarrow v \leq r(1-\alpha) \end{cases}$.

Hence, when $r > \dfrac{v}{1-\alpha}$, a solution exists

$$\begin{cases} p_{o,1}{}^{*} = v \\ p_o{}^{*} = \beta v \\ \pi^{*} = [\alpha+\delta(1-\alpha)\beta]v - [\alpha+(1-\alpha)\delta]vc \end{cases}$$, where (1) and (2) are binding.

(3) Leaders keep the original version and followers does not adopt with utilities:

$U_l = (1+\delta)v - p_{o,1}$ and $U_f = 0$.

This case arises when $\begin{cases} (1): U_l \geq 0 \Rightarrow p_{o,1} \leq (1+\delta)v \\ (2): U_f \geq \delta(\beta v + r\alpha - p_o) \Rightarrow p_o \geq \beta v + r\alpha \end{cases}$.

Hence, $\begin{cases} p_{o,1}{}^{*} = (1+\delta)v \\ \pi^{*} = \alpha(1+\delta)v - \alpha vc \end{cases}$.

(1) dominate (3) because we have $\beta \geq c$. Hence, the equilibrium is given by

$$p_{o,1}{}^{*} = \begin{cases} (1+\delta)v - \delta r(1-\alpha) & \text{when } v \geq (1-\alpha)r \\ v & \text{o/w} \end{cases},$$

$$p_o{}^{*} = \begin{cases} \beta v + r\alpha & \text{when } v \geq (1-\alpha)r \\ \beta v & \text{o/w} \end{cases}, \quad \pi^{*}_{NoNew} = \begin{cases} \pi^{(1)}_{NoNew} & \text{when } v \geq (1-\alpha)r \\ \pi^{(2)}_{NoNew} & \text{o/w} \end{cases},$$

where, $\pi^{(1)}_{NoNew} = [\alpha(1+\delta)+\delta(1-\alpha)\beta]v - [\alpha+(1-\alpha)\delta]vc$ and

$\pi^{(2)}_{NoNew} = [\alpha+\delta(1-\alpha)\beta]v - [\alpha+(1-\alpha)\delta]vc$.

Next we compare the firm's profits with the case of *Sequential Adoption*. It is easy to see that

$\pi_S^{(P-P)} > \pi_{NoNew}^{(2)}$ holds, $\pi_S^{(P-P)} > \pi_{NoNew}^{(1)}$ when $\Delta > \dfrac{c}{1-c}v$,

$$\pi_S^{(IC-P)} \geq \pi_{NoNew}^{(1)} \Leftrightarrow r \geq \frac{(v+\Delta)c+(v-\Delta)}{1-\alpha},$$

$$\pi_S^{(IC-P)} \geq \pi_{NoNew}^{(1)} \Leftrightarrow r \geq \frac{[\alpha+(1-\alpha)\beta]v-[\alpha+(1-\alpha)(1-\beta)]\Delta+\alpha(v+\Delta)c}{(1-\alpha)^2 d},$$

$$\pi_S^{(P-IC)} \geq \pi_{NoNew}^{(2)} \Leftrightarrow r \leq \frac{[1-(1-\alpha)\beta](v+\Delta)-\alpha(v+\Delta)c}{(1-\alpha)[1-(1-\alpha)d]}.$$

Define $\underline{r}^{new} = \min\left\{ \max\left\{ \begin{array}{l} \dfrac{(v+\Delta)c+(v-\Delta)}{1-\alpha}, \\ \dfrac{[\alpha+(1-\alpha)\beta]v-[\alpha+(1-\alpha)(1-\beta)]\Delta+\alpha(v+\Delta)c}{(1-\alpha)^2 d} \end{array} \right\}, \dfrac{v}{1-\alpha} \right\}$

$$\overline{r}^{new} = \max\left\{ \frac{[1-(1-\alpha)\beta](v+\Delta)-\alpha(v+\Delta)c}{(1-\alpha)[1-(1-\alpha)d]}, \frac{v}{1-\alpha} \right\}.$$

We the have $\pi_{NoNew}^{*} \leq \pi_S^{*}$ when $r \in (\underline{r}^{new}, \overline{r}^{new}]$.

Proof of Proposition 2:

From the optimal profits, we get

$$\frac{\partial \pi^{(IC-IC)}}{\partial d} = \frac{\partial \pi^{(P-IC)}}{\partial d} = r\delta(1-\alpha)^2 > 0, \quad \frac{\partial \pi^{(IC-P)}}{\partial d} = \frac{\partial \pi^{(P-P)}}{\partial d} = 0, \text{ and}$$

$$\frac{\partial \pi^{(IC-IC)}}{\partial \Delta} = \frac{\partial \pi^{(P-IC)}}{\partial \Delta} = \delta[\alpha(1-c)+(1-\alpha)(1-\beta)] > \frac{\partial \pi^{(IC-P)}}{\partial \Delta} = \frac{\partial \pi^{(P-P)}}{\partial \Delta} = \delta\alpha(1-c) > 0.$$

Proof of Lemma 2:

The *Sequential-Adoption* strategy can be re-written as

(I) For $r \leq \dfrac{v}{(1-\alpha)}$: For $\Delta \leq \dfrac{\beta v - r[d(1-\alpha)-\alpha]}{1-\beta}$, we have (IC-IC); otherwise, we have (IC-P).

(II) For $r > \dfrac{v}{(1-\alpha)}$: For $\Delta \leq \dfrac{r[(1-d)(1-\alpha)+\alpha]}{1-\beta} - v$, we have (P-IC); otherwise, we have

(P-P).

The optimal design (Δ^*, d^*) is derived by maximizing the firm's above optimal profits π^* net the development cost $K = k_1\Delta^2 + k_2 d^2$, i.e., $\pi^*(\Delta, d) - K(\Delta, d)$. Maximizing the respective profits $\pi^*(\Delta, d) - K(\Delta, d)$ under each pricing strategy in the absence of the above conditions for them to emerge gives unconstrained optimizers as follows:

$$\Delta^{(IC-IC)} = \frac{\delta[(1-\beta)+\alpha(\beta-c)]}{2k_1}, d^{(IC-IC)} = \frac{\delta r(1-\alpha)^2}{2k_2}, \Delta^{(IC-P)} = \frac{\delta\alpha(1-c)}{2k_1}, d^{(IC-P)} = 0,$$

$$\Delta^{(P-P)} = \frac{\delta\alpha(1-c)}{2k_1}, d^{(P-P)} = 0, \Delta^{(P-IC)} = \frac{\delta[(1-\beta)+\alpha(\beta-c)]}{2k_1}, d^{(P-IC)} = \frac{\delta r(1-\alpha)^2}{2k_2}.$$

We then have

(1) For $r \le \frac{v}{(1-\alpha)}$,

(a) For $\frac{\beta v - r[d^{(IC-P)}(1-\alpha)-\alpha]}{1-\beta} \le \Delta^{(IC-P)}$, or $v \le \frac{\delta\alpha(1-c)(1-\beta)}{2k_1\beta} - \frac{r\alpha}{\beta} \doteq \underline{v}$, we have

$$\Delta^* = \Delta^{(IC-P)}, d^* = d^{(IC-P)}.$$

(b) For $v \in [\underline{v}, \overline{v}]$,

$$\Delta^* = \frac{\beta v - r[d^{(a)}(1-\alpha)-\alpha]}{1-\beta} \doteq \Delta^{(a)},$$
$$d^* = \frac{r(1-\alpha)[2k_1(r\alpha+\beta v)-\alpha\delta(1-\beta)(1-c)]}{2[k_1 r^2(1-\alpha)^2 + k_2(1-\beta)^2]} \doteq d^{(a)}$$

(c) For $\frac{\beta v - r[d^{(IC-IC)}(1-\alpha)-\alpha]}{1-\beta} \ge \Delta^{(IC-IC)}$, or

$$v \ge \frac{\delta(1-\beta)[(1-\beta)+\alpha(\beta-c)]k_2}{2k_1k_2\beta} + \frac{\delta r^2(1-\alpha)^3}{2k_2\beta} - \frac{r\alpha}{\beta} \doteq \overline{v}$$, we have

$$\Delta^* = \Delta^{(IC-IC)}, d^* = d^{(IC-IC)}.$$

(2) For $r > \frac{v}{(1-\alpha)}$, we have

(a) For $\frac{r[(1-d^{(P-P)})(1-\alpha)+\alpha]}{1-\beta}-v \le \Delta^{(P-P)}$, or $v \ge \frac{r}{(1-\beta)}-\frac{\delta\alpha(1-c)(1-\beta)}{2k_1(1-\beta)} \doteq \overline{v}'$, we have

$$\Delta^* = \Delta^{(P-P)}, d^* = d^{(P-P)}.$$

(b) For $v \in [\underline{v}', \overline{v}']$,

$$\Delta^* = \frac{r[(1-d^{(b)})(1-\alpha)+\alpha]}{1-\beta}-v \doteq \Delta^{(b)},$$
$$d^* = \frac{r(1-\alpha)[2k_1(r-v+\beta v)-\alpha\delta(1-\beta)(1-c)]}{2[k_1 r^2(1-\alpha)^2+k_2(1-\beta)^2]} \doteq d^{(b)}.$$

(c) For $\frac{r[(1-d^{(P-IC)})(1-\alpha)+\alpha]}{1-\beta}-v \ge \Delta^{(P-IC)}$, or

$v \le \frac{2rk_2-\delta r^2(1-\alpha)^3}{2(1-\beta)k_2}-\frac{\delta(1-\beta)[(1-\beta)+\alpha(\beta-c)]k_2}{2(1-\beta)k_1k_2} \doteq \underline{v}'$, we have

$$\Delta^* = \Delta^{(P-IC)}, d^* = d^{(P-IC)}.$$

By defining

$$\overline{r} = \begin{cases} \text{larger root solving } v = \frac{\delta(1-\beta)[(1-\beta)+\alpha(\beta-c)]k_2}{2k_1k_2\beta}+\frac{\delta r^2(1-\alpha)^3}{2k_2\beta}-\frac{r\alpha}{\beta} & \text{for } r \le \frac{v}{(1-\alpha)} \\ \text{larger root solving } v = \frac{2rk_2-\delta r^2(1-\alpha)^3}{2(1-\beta)k_2}-\frac{\delta(1-\beta)[(1-\beta)+\alpha(\beta-c)]k_2}{2(1-\beta)k_1k_2} & \text{for } r > \frac{v}{(1-\alpha)} \end{cases}$$

and $\underline{r} = \begin{cases} \frac{\delta(1-c)(1-\beta)}{2k_1}-\frac{\beta v}{\alpha} & \text{for } r \le \frac{v}{(1-\alpha)} \\ \frac{\delta\alpha(1-c)(1-\beta)}{2k_1}+(1-\beta)v & \text{for } r > \frac{v}{(1-\alpha)} \end{cases}$, the optimal design can be rewritten as:

Parameter Range		Optimal Design
$r \le \underline{r}$	$v > (1-\alpha)r$	$\Delta^* = \Delta^{(IC-P)}, d^* = d^{(IC-P)}$
	$v \le (1-\alpha)r$	$\Delta^* = \Delta^{(P-P)}, d^* = d^{(P-P)}$
$r \in (\underline{r}, \overline{r}]$	$v > (1-\alpha)r$	$\Delta^* = \Delta^{(a)}, d^* = d^{(a)}$
	$v \le (1-\alpha)r$	$\Delta^* = \Delta^{(b)}, d^* = d^{(b)}$
$r > \overline{r}$	$v > (1-\alpha)r$	$\Delta^* = \Delta^{(IC-IC)}, d^* = d^{(IC-IC)}$

	$v \le (1-\alpha)r$	$\Delta^* = \Delta^{(P-IC)}, d^* = d^{(P-IC)}$

where, the optimal profits after design π_S^* in each of the four pricing schemes are given by,

$$\pi_S^{(IC-IC)} = \alpha v + \frac{\delta^2[(1-\beta)+\alpha(\beta-c)]^2}{4k_1} + \frac{\delta^2(1-\alpha)^4}{4k_2} r^2 - [\alpha+\delta(1-\alpha)]vc - \delta\alpha vc$$

$$\pi_S^{(IC-P)} = [\alpha+\delta(1-\alpha)\beta]v + \delta\alpha(1-\alpha)r + \frac{\delta^2\alpha^2(1-c)^2}{4k_1} - [\alpha+\delta(1-\alpha)]vc - \delta\alpha vc$$

$$\pi_S^{(P-P)} = [\alpha(1+\delta)+\delta(1-\alpha)\beta]v + \frac{\delta^2\alpha^2(1-c)^2}{4k_1} - [\alpha+\delta(1-\alpha)]vc - \delta\alpha vc$$

$$\pi_S^{(P-IC)} = (\alpha+\delta)v - \delta(1-\alpha)r + \frac{\delta^2[(1-\beta)+\alpha(\beta-c)]^2}{4k_1} + \frac{\delta^2(1-\alpha)^4}{4k_2} r^2 - [\alpha+\delta(1-\alpha)]vc - \delta\alpha vc$$

and the optimal profits in two transition regions (a) and (b) are given by:

$$\pi_S^{(a)} = \pi^{(IC-IC)}(\Delta^{(a)}, d^{(a)}) - K(\Delta^{(a)}, d^{(a)}) = \pi^{(IC-P)}(\Delta^{(a)}, d^{(a)}) - K(\Delta^{(a)}, d^{(a)})$$

$$\pi_S^{(b)} = \pi^{(P-P)}(\Delta^{(b)}, d^{(b)}) - K(\Delta^{(b)}, d^{(b)}) = \pi^{(P-IC)}(\Delta^{(b)}, d^{(b)}) - K(\Delta^{(b)}, d^{(b)})$$

Note that the subscript “*S*” denotes the *Sequential-Adoption* strategy.

Proof of Proposition 3:

Results immediately follow from Lemma 2.

Proof of Proposition 4:

Using a similar optimization model as in the *Sequential-Adoption* strategy, we can derive the firm’s equilibrium prices and profits in each of the other two targeting strategies, *Leap-Frog Adoption* and *Simultaneous Adoption*, as presented in Proposition A1 in the online supplement. The optimal design policy in each of the two targeting strategies is presented in Propositon A3 in the online supplement. Below, we first summarize the firm’s optiomal profits after design in each targeting strategy:

Under the *Leap-Frog-Adoption* strategy, the optimal design and profits are given as follows

(a) When $v \le (1-\alpha)r$,

$$(\Delta_L^*, d_L^*) = \begin{cases} \left(\frac{\delta(1-\alpha)(\beta-c)}{2k_1}, 1-\frac{v}{(1-\alpha)r}\right) & \text{when } r \geq \frac{\delta(1-\beta)(\beta-c)}{2k_1} + \frac{(1-\alpha)(1-\beta)-\alpha}{(1-\alpha)^2} v \\ \left(\frac{(1-\alpha)r}{(1-\beta)} + \left[\frac{\alpha}{(1-\beta)(1-\alpha)} - 1\right] v, 1-\frac{v}{(1-\alpha)r}\right) & \text{o/w} \end{cases}$$

with profits

$$\pi_L^* = \begin{cases} [\alpha(1-c)+\alpha\delta+(\beta-c)(1-\alpha)\delta]v + \frac{\delta^2(1-\alpha)^2(\beta-c)^2}{4k_1} - k_2\left(1-\frac{v}{r(1-\alpha)}\right)^2 \doteq \pi_L^{(4)} \\ \alpha(1-c+\delta)v + \frac{\delta[\alpha v+(1-\alpha)^2 r](\beta-c)}{1-\beta} - k_1\left(v - \frac{\alpha v+(1-\alpha)^2 r}{(1-\alpha)(1-\beta)}\right)^2 - k_2\left(1-\frac{v}{r(1-\alpha)}\right)^2 \doteq \pi_L^{(3)} \end{cases}$$

(b) For $v > (1-\alpha)r$,

$$(\Delta_L^*, d_L^*) = \begin{cases} \left(\frac{\delta(1-\alpha)(\beta-c)}{2k_1}, 0\right) & \text{when } r \geq \frac{\delta(1-\beta)(1-\alpha)(\beta-c)}{2\alpha k_1} - \frac{\beta v}{\alpha} \\ \left(\frac{r\alpha+\beta v}{1-\beta}, 0\right) & \text{o/w} \end{cases}$$

with profits

$$\pi_L^* = \begin{cases} [\alpha(1+\delta)+\delta(1-\alpha)\beta]v - [\alpha+\delta(1-\alpha)]vc + \frac{\delta^2(1-\alpha)^2(\beta-c)^2}{4k_1} \doteq \pi_L^{(1)} \\ \alpha(1+\delta)v + \frac{\delta(1-\alpha)\beta(v+\alpha r)}{1-\beta} - \alpha vc - \frac{\delta(1-\alpha)(v+\alpha r)c}{1-\beta} - k_1\frac{(\beta v+\alpha r)^2}{(1-\beta)} \doteq \pi_L^{(2)} \end{cases}$$

Note that the subscript "*L*" denotes the *Leap-Frog-Adoption* strategy.

Under the *Simultaneous-Adoption* strategy, the optimal design and profits are given as follows

$$(\Delta_M^*, d_M^*) = \begin{cases} \left(\frac{\delta(\beta-c)}{2k_1}, 0\right) & \text{for } r \leq \frac{(\beta-c)(1-\beta)\delta}{2\alpha k_1} + (1-\beta)v \\ \left(\frac{r}{1-\beta} - v, 0\right) & \text{for } r \in \left(\frac{(\beta-c)(1-\beta)\delta}{2\alpha k_1} + (1-\beta)v, \frac{(1-c)(1-\beta)\delta}{2\alpha k_1} + (1-\beta)v\right] \\ \left(\frac{\delta(1-c)}{2k_1}, 0\right) & \text{for } r > \frac{(1-c)(1-\beta)\delta}{2\alpha k_1} + (1-\beta)v \end{cases}$$

with profits

$$\pi_M^* = \begin{cases} \alpha(1-c)v + \delta[v(\beta-c)+r\alpha] + \frac{(\beta-c)^2\delta^2}{4k_1} \doteq \pi_M^{(1)} \\ \alpha(1-c)v + \alpha r\delta + \frac{\delta(\beta-c)r}{(1-\beta)} - \frac{[v(1-\beta)-r]^2 k_1}{(1-\beta)^2} \doteq \pi_M^{(2)} \\ \alpha(1-c)v + \delta[v(1-c)-r(1-\alpha)] + \frac{(1-c)^2\delta^2}{4k_1} \doteq \pi_M^{(3)} \end{cases}$$

Note that the subscript "*M*" denotes the *Simultaneous-Adoption* strategy.

We know

$$\frac{\partial \pi_S^{(IC-IC)}}{\partial v} = \alpha - (\alpha+\delta)c\,,\quad \frac{\partial \pi_S^{(IC-P)}}{\partial v} = \alpha + \delta(1-\alpha)\beta - (\alpha+\delta)c\,,$$

$$\frac{\partial \pi_S^{(P-P)}}{\partial v} = \alpha(1+\delta) + \delta(1-\alpha)\beta - (\alpha+\delta)c\,,\quad \frac{\partial \pi_S^{(P-IC)}}{\partial v} = (\alpha+\delta)(1-c)\,,$$

$$\frac{\partial \pi_M^{(1)}}{\partial v} = \alpha + \delta\beta - (\alpha+\delta)c\,,\quad \frac{\partial \pi_M^{(3)}}{\partial v} = (\alpha+\delta) - (\alpha+\delta)c\,,$$

$$\frac{\partial \pi_L^{(1)}}{\partial v} = \alpha + \beta\delta + \alpha\delta(1-\beta) + \alpha\delta c - (\alpha+\delta)c\,, \text{ and}$$

$$\frac{\partial \pi_L^{(4)}}{\partial v} = \alpha(1+\delta) + \delta(1-\alpha)\beta + \alpha\delta c - (\alpha+\delta)c + \frac{2k_2}{r(1-\alpha)}\left(1 - \frac{v}{r(1-\alpha)}\right).$$

Hence, for $v > (1-\alpha)r$, $\frac{\partial \pi_S^{(IC-IC)}}{\partial v}, \frac{\partial \pi_S^{(IC-P)}}{\partial v} < \frac{\partial \pi_M^{(1)}}{\partial v}, \frac{\partial \pi_M^{(3)}}{\partial v}$; and $\frac{\partial \pi_S^{(IC-IC)}}{\partial v}, \frac{\partial \pi_S^{(IC-P)}}{\partial v}, \frac{\partial \pi_M^{(1)}}{\partial v} < \frac{\partial \pi_L^{(1)}}{\partial v}$ hold. For $v \le (1-\alpha)r$, $\frac{\partial \pi_S^{(P-P)}}{\partial v} < \frac{\partial \pi_S^{(P-IC)}}{\partial v} = \frac{\partial \pi_M^{(3)}}{\partial v}$; and $\frac{\partial \pi_S^{(P-P)}}{\partial v}, \frac{\partial \pi_S^{(P-IC)}}{\partial v}, \frac{\partial \pi_M^{(3)}}{\partial v} < \frac{\partial \pi_L^{(4)}}{\partial v}$ hold. Therefore, when *v* is sufficiently large, *Leap-Frog Adoption* dominates the other two strategies, and *Sequential-Adoption* and *Simultaneous-Adoption* strategies emerge when *v* is not too large. Next, we show that when *Sequential Adoption* and *Simultaneous Adoption* are not dominated by *Leap-Frog Adoption*, *Sequential Adoption* dominates *Simultaneous Adoption* at very low and very high *r*, and *Simultaneous Adoption* dominates *Sequential Adoption* at intermediate *r*. This is because when $v \le (1-\alpha)r$, at low *r*, $\frac{\partial \pi_M^{(1)}}{\partial r} = \delta\alpha > \frac{\partial \pi_S^{(P-P)}}{\partial r} = 0$; at high *r*, $\frac{\partial \pi_M^{(3)}}{\partial r} = -\delta(1-\alpha) + \frac{(1-c)^2\delta^2}{4k_1} < \frac{\partial \pi_S^{(P-IC)}}{\partial r} = -\delta(1-\alpha) + \frac{\delta^2(1-\alpha)^4}{2k_2} r (<0)$ when *r* is sufficiently high. Also, note that the strategy of not introducting a new product is always dominated by the *Leap-Frog-Adoption* strategy, in which the firm could leverage the same level of reference-group effect by offering a new product with zero exterior differentiation, but is able to make higher profits by making followers adopt a new version with higher functionality.