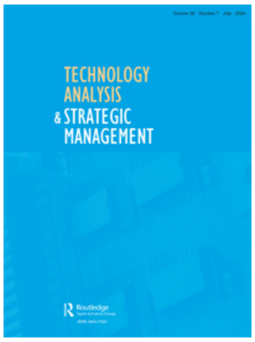

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Price and durability decisions on successive generations of electronic durable goods under incremental innovation

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ABSTRACT

This research explores the decision-making processes of manufacturers regarding pricing and durability of electronic durable products across successive generations. By constructing a two-stage model, we derived the optimal pricing strategy and production strategy for manufacturers. Specifically, we considered the impact of price reductions on older products and pre-launch activities for new products on consumer behavior, especially that of strategic consumers. An interesting finding is that traditional sales strategies of discounting older products do not increase revenue, but rather harm overall profits. Our results provide guidance for manufacturers of electronic durable goods in formulating strategies for product upgrades and new product sales strategies.

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Incremental innovation; strategic consumer; durability; electronic durable goods

1. Introduction

Consumers are increasingly purchasing electronic durables, such as mobile phones and laptops, driven by the rapid release of new generations from high-tech companies. Apple's annual release of new iPhones and iPads is a typical example of this trend. According to the life cycle model, industries transition into an 'era of incremental change' characterized by stability and minimal innovation once a dominant design has been established (Lee and Berente 2013). In the electronic durables sector, each new iteration brings incremental technological innovations, enhancing performance and features over its predecessors. Decision-making for consumers in this market has become increasingly complex, influenced by a range of factors. Even though they do not always choose the latest generation, consumers weigh utility, enhancements, and price points in their purchasing decisions. In 2017, Apple reported that 63% of all iPhones sold were still operational, with the iPhone 7 (Plus) accounting for 19% and the earlier iPhone 6S (Plus) for 26%. Notably, about 50% of functioning iPhones, or approximately 370 million units, were models released in 2014 or before (Celebrating 10 Years of iPhones 2017; Leading Apple iPhone 2020). This prolonged smartphone lifecycle presents a challenge to manufacturers and impacts sales of new devices.

Montez (2013) introduced a novel explanation for unscheduled price cuts and the slow adoption of durable goods. Typically, electronic durables are initially priced high, leading buyers to anticipate future price reductions and delay their purchases. Alternatively, Seidl, Hartl, and Kort (2019) suggested maintaining a constant price for each product generation post-launch, which removes the incentive for consumers to wait for price drops. Consequently, the pricing strategy for earlier generation products significantly influences consumer purchasing decisions.

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Durability is another crucial factor affecting the sales of new generation products. Companies often implement a 'planned obsolescence' strategy, deliberately reducing product durability through measures such as software incompatibility and battery limitations (Swan 1972; Amankwah-Amoah 2017). For instance, in January 2020, Apple announced which iPhones would receive updates in that year, categorizing older models like the iPhone 6 as 'obsolete' in terms of software support. By designing products with shorter lifespans, firms aim to drive higher revenues and profits in saturated and highly competitive markets (Guiltinan 2009; Gershoff, Kivetz, and Keinan 2012). However, while this strategy may lead to higher profits, it also negatively affects customers' perceptions of value and their willingness to pay (Kuppelwieser et al. 2019).

Therefore, the discussion on the pricing strategy and durability of successive gene rations of electronic durables is a challenging yet valuable topic. As companies launch new products, consumers face the decision of buying the latest version immediately or waiting for potential discounts on forthcoming models. Through extensive product reviews on the Internet and advanced pre-release information from manufacturers, strategic consumers actually can obtain accurate price forecasts and gain insight into forthcoming technological improvement (Zhang and Zhang 2017). Thus, it is crucial to integrate the decision-making patterns of strategic consumers into the production strategies of manufacturers of electronic durables (Aviv and Pazgal 2008; Liu, Zhai, and Chen 2019).

In this paper, we assume that all consumers are strategic. Building on an analysis of strategic consumer purchasing behavior, we have derived optimal production and pricing strategies for manufacturers of electronic durables. Specifically, we discuss the following questions:

1. How do strategic consumers make purchasing decisions during the launch of two successive product generations?
2. Considering the industry's 'incremental innovation' theme, what is the optimal strategy for firms to invest in the durability of emerging products?
3. To maximize sales profit, what is the optimal pricing strategy when considering discounts on older generation products?

By addressing these questions, we aim to fill a gap in current research, specifically examining strategic consumer behavior in response to successive product generations. Our study primarily focuses on the purchasing decisions made after consumers receive technical information and form price expectations during the pre-launch phase. Different from previous studies, we investigate changes in consumer psychology and behavior triggered by manufacturers' pre-launch activities, which may lead consumers to adopt a waiting approach and possibly choose the previous generation post-launch in anticipation of price reductions. This research has practical importance as it assists enterprises in making informed production decisions that consider the interaction between businesses and consumers.

The paper is organized as follows: Section 2 reviews relevant literature. Section 3 explains and analyzes our fundamental model. Section 4 computes and discusses decisions made by an electronic durables firm. Section 5 summarizes the conclusions drawn from our study.

2. Literature review

The landscape of electronic durable goods has garnered substantial attention from researchers, with investigations primarily unfolding through two critical lenses – the perspective of manufacturers and that of consumers.

2.1. Manufactures-oriented literature

The manufacturers-oriented literature delves into the intricate web of production determinations, focusing on pricing, durability, and the management of durable goods inventory. Dhebar (1994) was a pioneering scholar who scrutinized the production decision problem of electronic durable goods, recognizing the rapid evolution of products like computer hardware and telecommunications equipment. His two-stage model highlighted how rational consumers decide when to embrace new products in the face of continuous introductions, emphasizing the lack of equilibrium strategy when technological changes outpace manufacturers' abilities. Subsequent research built on this foundation, exploring various dimensions of manufacturers' strategies. Kornish (2001) navigated the pricing problem of a monopolist frequently upgrading products, establishing equilibrium pricing strategies and unraveling the dynamics of upgrade pricing. Choudhary et al. (2005) ventured into the duopoly market model, revealing the intricate dance between customer sensitivity to quality and the establishment of pricing models involving quality discrimination for different consumers. Ray, Boyaci, and Aras (2005) focused on optimal pricing and trade-in strategies for durable, remanufacturable products, exploring diverse pricing schemes and their implications on profits. Bala and Carr (2009) delved into upgrade pricing in a two-stage framework, while Yin et al. (2010) highlighted the emergence of the P2P used goods market, influencing the introduction of new product versions and retail prices. Motivated by collaborations with telecommunications equipment manufacturers, Li and Graves (2012) formulated dynamic pricing problems, deriving optimal prices for both old and new products during a product transition. Subsequent studies by Liu, Zhai, and Chen (2019), Hu, Zhu, and Fu (2023), Sim, Oh, and Huh (2021), Kirkizoğlu and Karaer (2022), Fang (2020), and Li et al. (2022) further explored optimal pricing strategies, trade-in and refurbishment tactics, the role of pricing policies in consumer behavior, and post-sales services in the realm of durable goods.

2.2. Consumers-oriented literature

Another strand of literature approaches the subject from the consumer's standpoint, seeking insights into the decision-making processes surrounding the purchase of durable goods. Okada (2001) highlights that the replacement decision of a consumer contemplating upgrading to a newer, superior product is shaped by a combination of normative economic factors and psychological considerations. Grewal, Mehta, and Kardes (2004) propose that attitude functions, encompassing knowledge, value expression, social adjustment, and utilitarian aspects, offer valuable frameworks to comprehend and forecast interpurchase intervals. Okada (2006) further explores the positioning of enhanced products relative to existing ones, aiming to alleviate psychological costs and facilitate upgrade purchases. Desai, Koenigsberg, and Purohit (2007) contribute a dynamic model to understand durable product markets amid demand uncertainty, while Gowrisankaran and Rysman (2012) specify a dynamic model capturing consumer preferences for new durable goods characterized by persistently heterogeneous tastes, rational expectations, and repeat purchases over time. Empirical studies by Kumar and Kaushal (2019) reveal that perceived quality, price consciousness, brand consciousness, perceived risk, and advertising significantly influence consumer attitudes and subsequent behavior in the context of electronic durable goods. As consumer behavior research advances, scholars like Anderson and Wilson (2003), Su and Zhang (2009), and Farshbaf-Geranmayeh and Zaccour (2021) direct their focus to two distinct consumer categories: strategic consumers and myopic consumers.

Notably, in scenarios where companies continually release new generations of products to strategic consumers, the existing literature often overlooks the crucial factor of information disclosure before product launches. This oversight stands in contrast to prevalent industry practices. Thus, our primary focus revolves around understanding strategic consumers' decision-making in the context of incremental innovation and rapid replacement, shedding light on the intertwined dynamics of pricing and durability decisions made by electronic durable goods firms.

3. Proposed model

Electronic durables firms often adopt an 'incremental innovation' approach, sequentially launching new products. Let's consider an electronic durables firm that introduces a product (Production 1) at time 0, and plans to unveil the next generation (Production 2) at time T. As part of their marketing strategies, the firm engages in preheating by revealing key information, including durability, about the upcoming product before its official launch. This approach aims to generate greater interest. Assume that the information disclosure occurs at time t, where $t \in [0, T]$. Among the various parameters, durability holds considerable importance, as it significantly influences consumers' purchasing decisions. Striking a balance between costs and performance, some consumers opt to buy Product 1 immediately upon its release, while others opt to wait for the subsequent generation, i.e. Product 2. During the preheating period for Product 2, the firm might offer a discount rate τ to expedite the sales of Product 1. Consumers receive fresh insights into the durability and pricing of both Product 1 and Product 2. Consequently, a subset of consumers may choose to capitalize on the discount and acquire Product 1, while others opt to hold out for the launch of Product 2. Figure 1 illustrates the chronological sequence of the firm's decision-making process.

Hence, we have formulated a model aimed at addressing the intricate challenge of how electronic durables companies determine their pricing and durability strategies while accounting for the impact of durability decay and strategic consumer behavior. In order to align with real-world scenarios, we establish the assumption that consumers would opt to purchase either Product 1 or Product 2 exclusively, or alternatively, they might choose not to make a purchase and exit the market altogether. For the purpose of this study, we omit the consideration of the used goods market. Based on the insights derived from the analysis presented in the introduction and literature review, a reasonable assumption can be made that every consumer within the electronic durables market exhibits a strategic behavior. The anticipated utility of consuming a product is intricately linked to factors such as its price, durability, and the individual's subjective willingness to pay for the product. The firm decides the price of two generations products devoted by p_i, $i \in \{1, 2\}$. We set the durability of product 1 as d_1 and devote by d_2, the durability of product 2 set by the firm. According to Bala and Carr (2009), Krishnan and Ramachandran (2011), the firm's unit production cost is normalized to zero. ϵ represents the willingness to pay (WTP) by consumers for the product and ϵ is uniformly distributed over [0, 1]. Key notations in this paper are summarized in Table 1.

Take U_{ij} as the expected utility of product i at time j. The utility function of strategic consumers for product 1 at time 0 is

$$U_{10} = d_1 - p_1 + \epsilon \tag{1}$$

When $U_{10} > 0$, consumers will purchase Product 1 at time 0. Otherwise, they will delay their purchases. At time t, Product 2' information will be released at time t, and then the company will reduce the price of the first generation of products. Hence, the utility of Product 1 after the price markdown at time t can be expressed as

$$U_{1t} = d_1 - \tau p_1 + \epsilon \tag{2}$$

τ is the discount rate on the price of products, $\tau \in [0, 1]$. At time t, consumers can also predict the future utility U_{2T} of Product 2 based on the information and compare it with the utility of Product 1 after the discount. The expected utility of Product 2 at time T can be expressed as

$$U_{2T} = \delta(d_2 - p_2 + \epsilon)$$

δ is the discount factor with respect to time. According to the decision-making process of consumers, we can know that when Product 1 is launched, consumers cannot predict the future price

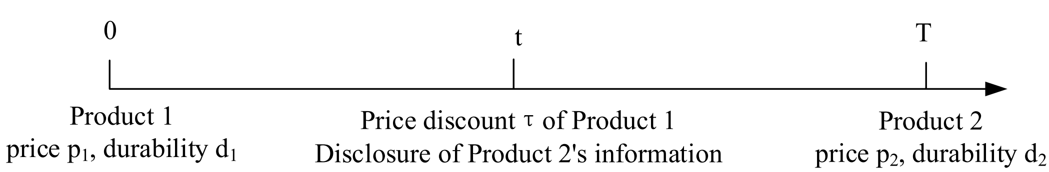

Figure 1. Timeline of the decision-making process of electronic durables firms.

Table 1. Parameters and decision variables.

Symbol	Description
p_i	Price of Product i
d_i	Durability of Product i
U_{it}	Consumer utility for Product i at time t, $t \in [0, T]$
D_{it}	Demands for Product i at time t
M	The size of the market
τ	Discount rate of price for the former generation product
ϵ	Consumers' basic willingness to pay for the product
β_i	The cost coefficient of investment on product durability
δ	Discount factor with respect to time

trend of the product and the situation of the new product. Therefore, consumers will buy the product as long as its utility is positive, i.e $U_{10} > 0$. We assume there is a threshold value when $U_{10} > 0$, that is, $\epsilon > \epsilon_1 = p_1 - d_1$. Similarly, at time t, there is utility comparison between U_{1t} and U_{2T} because consumers know the information of the new product. Therefore, there is also a threshold $\epsilon_2 = \max\left\{\frac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta}, \tau p_1 - d_1\right\}$ when $U_{1t} = U_{2T}$. If $\epsilon > \epsilon_2$, consumer will purchase the discounted product 1. Otherwise, consumers will wait to buy new products. At time T, consumers will purchase product 2 if $U_{2T} > 0$ and $\epsilon > \epsilon_3 = p_2 - d_2$. It is important that we do not know the size relationship of three thresholds, and so we will analyze by discussing different cases below.

We segment the market according to the expected utility divide consumers into four situations according to their consumption utility: those who would purchase Product 2, Product 1 at full price and Product 1 after discount, and do not buy any products.

For ease of calculation, we set the market size M to 1. We set D_{10}, D_{1t}, D_{2T} as the demand of the product at each moment, and can obtain the target revenue function should be

$$\Pi = \max_{\substack{p_1, d_1 \\ p_2, d_2}} \ (p_1 - \beta_1 d_1)D_{10} + (\tau p_1 - \beta_1 d_1)D_{1t} + (p_2 - \beta_2 d_2)D_{2T}$$

Given the scenario of this paper, we focus on the short period during the release of two successive generations of products. Due to consumers' expectations, manufacturer information disclosure, etc., consumers' purchase behavior would especially change by p_i and d_i, therefore we focus on four variables p_1, p_2, d_1, d_2 .

The unit cost of the durability improvement investment of the corresponding product $\beta_i d_i$. β_i is a positive parameter that denotes the cost coefficient of investment on product durability. Through the optimization of product pricing and durability enhancement, the optimal revenue for the firm can be derived. The subsequent section will provide a comprehensive account of the detailed optimization process.

4. Analysis and simulation

4.1. Mathematical analysis

We now delve into the circumstances under which the firm's objective function attains optimality. Initially, at time 0, when Product 1 is freshly introduced and consumers lack information about the upcoming generation and any potential future discount rates for Product 1, their decision to purchase Product 1 hinges solely on whether the expected utility surpasses zero. Consequently, consumers are likely to buy Product 1 at this point in time.

As the preheating phase for Product 2 commences at time t, pertinent information becomes accessible. Consumers acquire an expected utility for both Product 2 and Product 1, which is now offered at a discounted price. During this juncture, consumers engage in a comparative analysis. If the utility of Product 1 at time t exceeds the expected utility of Product 2 at time T, they opt to purchase Product 1 at the discounted rate. On the contrary, if the utility of Product 2 at time T appears more promising, they choose to wait until time T to acquire Product 2, or alternatively, they might decide to exit the market altogether.

Through this process, three crucial values can be ascertained as follows.

When $\epsilon > \epsilon_1 = p_1 - d_1 > 0$, consumers buy product 1 at time 0. When $\epsilon > \epsilon_2 = \max\left\{\frac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta}, \tau p_1 - d_1\right\}$, consumers buy product 1 at time t. When $\epsilon > \epsilon_3 = p_2 - d_2 > 0$, consumers buy product 2 at time T. However, it is worth noting that we do not know the size of the three thresholds, so we will analyze and discuss several different situations to compare the threshold size and the company's profits.

Case 1: When $0 \le \epsilon_1 \le \epsilon_2 \le \epsilon_3 \le 1$, this means that the demand of consumers is at time 0 is $1 - \epsilon_1$. At this point, the demand at time t and time T is $\emptyset$. Consumer demand can be expressed as

$$D_{10} = 1 - \epsilon_1 = 1 - p_1 + d_1$$

$$D_{1t} = \emptyset$$

$$D_{2T} = \emptyset$$

In this case, the firm's profit function and constraints for the optimal solution are

$$\Pi_1 = \max_{p_1,\, d_1} \ (p_1 - \beta_1 d_1) D_{10} = \max_{p_1,\, d_1} \ (p_1 - \beta_1 d_1)(1 - p_1 + d_1)$$

s.t. $0 \le \epsilon_1 \le \epsilon_2 \le \epsilon_3 \le 1$

We know that the target function Π_1 is a quadratic function of $p_1,\ d_1$. The optimal solution must satisfy the above constraint conditions. Therefore, by resolving the constraint conditions, we can judge whether the case the optimal solution.

Firstly, we make assumptions about the range of relevant parameters and variables according to the actual situation, $p_i, d_i > 0$ and $\tau,\ \delta \in [0, 1]$. Next, we verify whether the optimal solution conforms to the constraints.

(1) When $0 \le \epsilon_1 \le 1$,
there is $0 \le p_1 - d_1 \le 1$, that is $1 - p_1 \le d_1 \le p_1$.

(2) When $\epsilon_1 \le \epsilon_2$,
there is $p_1 - d_1 \le \max\left\{\frac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta}, \tau p_1 - d_1\right\}$. Obviously, when $0 < \tau < 1$, we obtain that $p_1 - d_1 \le \frac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta}$ and

$$d_1 \le \frac{\delta(d_2 - p_2) + (\tau - 1 + \delta)p_1}{\delta} = G_1.$$

(3) When $\epsilon_2 \le \epsilon_3$,
there is $\max\left\{\frac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta}, \tau p_1 - d_1\right\} \le p_2 - d_2$. When $0 < \tau < 1$, we acquire that $\frac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta} \le p_2 - d_2$ and

$$d_1 \ge \tau p_1 - p_2 + d_2 = G_2$$

(4) When $0 < \epsilon_3 \le 1$, there is $0 < p_2 - d_2 \le 1$.

Now, our main task is to compare the size of G_1, G_2 and only when $G_2 < G_1$. When $\delta = 1$, it's easy to get $G_1 = G_2$. We assume G_1 is a function about δ as follows.

$$G_1(\delta) = \frac{\delta(d_2 - p_2) + (\tau - 1 + \delta)p_1}{\delta} = d_2 - p_2 + \frac{(\tau - 1)p_1}{\delta} + p_1$$

According to $\tau < 1$, we can judge that $G_1(\delta)$ is a monotonically increasing function. At this point, for any parameter conforming to the constraint conditions, when $\delta < 1$, there is $G_1(\delta) < G_1(1) = G_2$. Therefore, the constraint conditions themselves are contradictory, so the range of optimal solution cannot be obtained and there is no solution in Case 1.

Case 2: When $0 \le \epsilon_1 \le \epsilon_3 \le \epsilon_2 \le 1$, The consumer will only buy Product 1 at time 0, and the demand at time t and time T is $\emptyset$.

$$D_{10} = 1 - \epsilon_1$$

$$D_{1t} = \emptyset$$

$$D_{2T} = \emptyset$$

The objective function is

$$\Pi_2 = \max_{p_1,\, d_1} \ (p_1 - \beta_1 d_1)D_{10} = \max_{p_1,\, d_1} \ (p_1 - \beta_1 d_1)(1 - p_1 + d_1)$$

s.t. $0 \le \epsilon_1 \le \epsilon_3 \le \epsilon_2 \le 1$

The calculation is similar as case 1 and our analysis of the constraints is as follows:

(1) When $0 \le \epsilon_1 \le 1$,
there is $0 \le p_1 - d_1 \le 1$， that is $1 - p_1 \le d_1 \le p_1$.

(2) When $\epsilon_1 \le \epsilon_3$,
there is $p_1 - d_1 \le p_2 - d_2$ and we assume that

$$d_1 \ge p_1 - p_2 + d_2 = G_1.$$

(3) When $\epsilon_3 \le \epsilon_2$,
there is $p_2 - d_2 \le \max\left\{\frac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta}, \tau p_1 - d_1\right\}$. When $0 < \tau < 1$, we acquire that $p_2 - d_2 \le \frac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta}$ and

$$d_1 \le \tau p_1 - p_2 + d_2 = G_2.$$

(4) When $0 < \epsilon_2 \le 1$,
there is $0 < \frac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta} \le 1$ and the values of d_1 are in the following range

$$\delta(d_2 - p_2) + \tau p_1 - (1 - \delta) \le d_1 \le \delta(d_2 - p_2) + \tau p_1.$$

Obviously, when $\tau\langle 1$, there must be $G_1\rangle G_2$. Therefore, in Case 2, we cannot obtain the value range of the optimal solution and we cannot obtain the optimal solution in this case.

Case 3: When $0 < \epsilon_2 < \epsilon_1 < \epsilon_3 < 1$, the consumer will buy the product at time 0 and time t. The demand are as follows:

$$D_{10} = 1 - \epsilon_1$$

$$D_{1t} = \epsilon_1 - \epsilon_2$$

$$D_{2T} = \emptyset$$

In this case, the objective function is

$$\Pi_3 = \max_{p_1, d_1} \ (p_1 - \beta_1 d_1)(1 - \epsilon_1) + \ (\tau p_1 - \beta_1 d_1)(\epsilon_1 - \epsilon_2)$$

s.t $0 < \epsilon_2 < \epsilon_1 < \epsilon_3 < 1$

First, we judge whether the constraint conditions are satisfied, and then find the optimal solution of the objective function. The correlation analysis of constraint conditions is as follows:

(1) When $0 \le \epsilon_2 \le 1$ and $\tau < 1$, $0 \le \dfrac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta} \le 1$ can be written as

$$\delta(d_2 - p_2) + \tau p_1 - (1 - \delta) \le d_1 \le \delta(d_2 - p_2) + \tau p_1$$

We assume

$$d_1 \le \delta(d_2 - p_2) + \tau p_1 = G_1.$$

(2) When $\epsilon_2 \le \epsilon_1$,

there is $\dfrac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta} \le p_1 - d_1$ and we assume that

$$d_1 \ge \frac{\delta(d_2 - p_2) + (\tau - 1 + \delta)p_1}{\delta} = G_2.$$

(3) When $\epsilon_1 \le \epsilon_3$,

there is $p_1 - d_1 \le p_2 - d_2$. We assume

$$d_1 \ge d_2 - p_2 + p_1 = G_3.$$

(4) When $0 < \epsilon_3 \le 1$,

there is $0 < p_2 - d_2 \le 1$ and obviously we compare between G_1 and G_3, which can obtain that $G_1 < G_3$. So we can't get a valid solution.

Case 4: When $0 < \epsilon_2 < \epsilon_3 < \epsilon_1 < 1$, the consumer will buy the product at time 0 and time T. In this case, the demand of Product 1and Product 2 are

$$D_{10} = 1 - \epsilon_1$$

$$D_{1t} = \epsilon_1 - \epsilon_2$$

$$D_{2T} = \emptyset$$

The objective function is

$$\Pi_4 = \max_{p_1, d_1} \ (p_1 - \beta_1 d_1)(1 - \epsilon_1) + \ (\tau p_1 - \beta_1 d_1)(\epsilon_1 - \epsilon_2)$$

s.t. $0 < \epsilon_2 < \epsilon_3 < \epsilon_1 < 1$

The correlation analysis of constraint conditions is as follows:

(1) When $0 \le \epsilon_2 \le 1$ and $\tau < 1$, $0 \le \dfrac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta} \le 1$ can be written as

$$\delta(d_2 - p_2) + \tau p_1 - (1 - \delta) \le d_1 \le \delta(d_2 - p_2) + \tau p_1$$

We assume

$$d_1 \le \delta(d_2 - p_2) + \tau p_1 = G_1.$$

(2) When $\epsilon_2 \le \epsilon_3$,

there is $\dfrac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta} \le p_2 - d_2$ and we assume that

$$d_1 \ge \tau p_1 - p_2 + d_2 = G_2.$$

(3) When $\epsilon_3 \le \epsilon_1$,

there is $p_2 - d_2 \le p_1 - d_1$. We assume

$$d_1 \le d_2 - p_2 + p_1 = G_3.$$

(4) When $0 < \epsilon_1 \leq 1$,
there is $0 < p_1 - d_1 \leq 1$ and obviously we compare between G_3 and G_2, which can obtain that $G_3 < G_2$. So we can't get a valid solution.

Case 5: When $0 < \epsilon_3 < \epsilon_1 < \epsilon_2 < 1$, consumers only have demand at time 0 and time t.

$$D_{10} = 1 - \epsilon_1$$

$$D_{1t} = \emptyset$$

$$D_{2T} = \epsilon_1 - \epsilon_3$$

The objective function is

$$\Pi_5 = \max_{\substack{p_1,d_1\\p_2,d_2}} \ (p_1 - \beta_1 d_1)D_{10} + (p_2 - \beta_2 d_2)D_{2T}$$

$$= \max_{p_1,d_1} \ (p_1 - \beta_1 d_1)(1 - p_1 + d_1) + (p_2 - \beta_2 d_2)(p_1 - d_1 - p_2 + d_2)$$

s.t. $0 < \epsilon_3 < \epsilon_1 < \epsilon_2 < 1$

(1) When $0 \leq \epsilon_3 \leq 1$,

$$0 \leq p_2 - d_2 \leq 1.$$

(2) When $\epsilon_3 \leq \epsilon_1$,
there is $p_2 - d_2 \leq p_1 - d_1$ and we assume that

$$d_1 \leq d_2 - p_2 + p_1 = G_1.$$

(3) When $\epsilon_1 \leq \epsilon_2$,
there is $p_1 - d_1 \leq \dfrac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta}$. We assume

$$d_1 \leq \frac{\delta(d_2 - p_2) + (\tau - 1 + \delta)p_1}{\delta} = d_2 - p_2 + p_1 + \frac{(\tau - 1)p_1}{\delta} = G_2.$$

(4) When $0 < \epsilon_2 \leq 1$,
there is $0 < \dfrac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta} \leq 1$, and

$$\delta(d_2 - p_2) + \tau p_1 - (1 - \delta) \leq d_1 \leq \delta(d_2 - p_2) + \tau p_1.$$

We compare between G_2 and G_1. Obviously, $G_2 < G_1$. In this case, the value range of d_1 can be obtained.

$$\delta(d_2 - p_2) + \tau p_1 - (1 - \delta) \leq d_1 \leq \min\left\{\delta(d_2 - p_2) + \tau p_1, d_2 - p_2 + p_1 + \frac{(\tau - 1)p_1}{\delta}\right\}$$

Then we get the equilibrium solution by taking the derivative of the objective function Π_5. We first calculate the first partial derivative of the objective function respectively for the four variables as follows:

$$\frac{\partial \Pi_5}{\partial p_1} = 1 + d_1 - 2p_1 + p_2 + d_1\beta_1 - d_2\beta_2$$

$$\frac{\partial \Pi_5}{\partial d_1} = p_1 - p_2 - d_1\beta_1 - (1 + d_1 - p_1)\beta_1 + d_2\beta_2$$

$$\frac{\partial \Pi_5}{\partial p_2} = -d_1 + d_2 + p_1 - 2p_2 + d_2\beta_2$$

$$\frac{\partial \Pi_5}{\partial d_2} = p_2 - d_2\beta_2 - (-d_1 + d_2 + p_1 - p_2)\beta_2$$

Then, the equations obtained from the first partial derivative are all equal to 0, and the optimal solution of the objective function is obtained.

$$p_1 = \frac{\beta_1}{-1 + \beta_1}; d_1 = \frac{1}{-1 + \beta_1}; p_2 = \frac{\beta_2}{-1 + \beta_2}; d_2 = -\frac{1}{1 - \beta_2};$$

We bring the results of the above solution back to the objective function and find that the maximum value of the objective function is 0. So we also can't get a valid solution in case 5.

Case 6: When $0 < \epsilon_3 < \epsilon_2 < \epsilon_1 < 1$, the demand of consumers at each moment is

$$D_{10} = 1 - \epsilon_1$$

$$D_{1t} = \epsilon_1 - \epsilon_2$$

$$D_{2T} = \epsilon_2 - \epsilon_3$$

The objective function is

$$\Pi_6 = \max_{\substack{p_1,d_1 \\ p_2,d_2}} (p_1 - \beta_1 d_1)D_{10} + (\tau p_1 - \beta_1 d_1)D_{1t} + (p_2 - \beta_2 d_2)D_{2T}$$

$$= \max_{\substack{p_1,d_1 \\ p_2,d_2}} (p_1 - \beta_1 d_1)(1 - \epsilon_1) + (\tau p_1 - \beta_1 d_1)(\epsilon_1 - \epsilon_2) + (p_2 - \beta_2 d_2)(\epsilon_2 - p_2 + d_2)$$

s.t. $0 < \epsilon_3 < \epsilon_2 < \epsilon_1 < 1$

Similarly, we first analyze the constraint conditions, and the results are as follows.

(1) When $0 \le \epsilon_1 \le 1$,

$$0 \le p_1 - d_1 \le 1.$$

(2) When $\epsilon_2 \le \epsilon_1$,

there is $\frac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta} \le p_1 - d_1$ and we assume that

$$d_1 \ge \frac{\delta(d_2 - p_2) + (\tau - 1 + \delta)p_1}{\delta} = G_1.$$

(3) When $\epsilon_3 \le \epsilon_2$,

there is $p_2 - d_2 \le \max\left\{\frac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta}, \tau p_1 - d_1\right\}$. When $0 < \tau < 1$, we acquire that $p_2 - d_2 \le \frac{\delta(d_2 - p_2) + \tau p_1 - d_1}{1 - \delta}$ and

$$d_1 \le \tau p_1 - p_2 + d_2 = G_2.$$

(4) When $0 < \epsilon_3 \leq 1$,

$$0 < p_2 - d_2 \leq 1.$$

In this case, the value range of d_1 can be obtained.

$$\frac{\delta(d_2 - p_2) + (\tau - 1 + \delta)p_1}{\delta} \leq d_1 \leq \tau p_1 - p_2 + d_2$$

Similarly, taking the first partial derivatives of the four variables p_1, d_1, p_2,d_2.

$$\frac{\partial \Pi_6}{\partial p_1} = \frac{(2 - 2\delta - 2\tau + 2\delta\tau + 2\tau^2)p_1 + -1 + \delta - \tau p_2 - \delta\tau p_2 - d_1(1 + \delta(-1 + \tau) + \tau\beta_1) + \tau d_2(\delta + \beta_2)}{-1 + \delta}$$

$$\frac{\partial \Pi_6}{\partial d_1} = \frac{\beta_1 - \delta\beta_1 + 2d_1\beta_1 - \delta d_2\beta_1 + p_2(1 + \delta\beta_1) - p_1(1 + \delta(-1 + \tau) + \tau\beta_1) - d_2\beta_2}{-1 + \delta}$$

$$\frac{\partial \Pi_6}{\partial p_2} = \frac{\tau p_1 + \delta\tau p_1 - 2p_2 - d_1(1 + \delta\beta_1) + d_2(1 + \beta_2)}{1 - \delta}$$

$$\frac{\partial \Pi_6}{\partial d_2} = \frac{\delta d_1\beta_1 + d_1\beta_2 - 2d_2\beta_2 + p_2(1 + \beta_2) - \tau p_1(\delta + \beta_2)}{1 - \delta}$$

Then, make them equal to 0 respectively for the above objective function, and then combine the equations, the optimal solution can be obtained.

$$p_1^* = \frac{\beta_1(-1 + \tau\beta_1)}{1 + (-4 + 6\tau - 4\tau^2)\beta_1 + \tau^2\beta_1^2}$$

$$p_2^* = \frac{\beta_2 + \beta_1^2(\delta(2 - 3\tau + \tau^2) + \tau^2\beta_2) + \beta_1(\delta(-1 + \tau) - 2(1 - \tau + \tau^2)\beta_2)}{(1 + (-4 + 6\tau - 4\tau^2)\beta_1 + \tau^2\beta_1^2)(-1 + \beta_2)}$$

$$d_1^* = \frac{-1 + (2 - 3\tau + 2\tau^2)\beta_1}{1 + (-4 + 6\tau - 4\tau^2)\beta_1 + \tau^2\beta_1^2}$$

$$d_2^* = \frac{1 + (\delta(-1 + \tau) - 2(1 - \tau + \tau^2))\beta_1 + (\tau^2 + \delta(2 - 3\tau + \tau^2))\beta_1^2}{(1 + (-4 + 6\tau - 4\tau^2)\beta_1 + \tau^2\beta_1^2)(-1 + \beta_2)}$$

Then we bring the above results back to the objective function to obtain the optimal solution of the objective function.

$$\Pi_6 = \frac{(-1 + \tau)^2\beta_1^2}{-1 + (4 - 6\tau + 4\tau^2)\beta_1 - \tau^2\beta_1^2}$$

The aforementioned calculation results reveal that the optimal solution of the objective function aligns more closely with the observed outcomes in Case 6. To facilitate a more precise assessment of the impact of each parameter on the outcomes, a numerical simulation will be conducted in the subsequent section.

4.2. Numerical simulation

In this section, we formulate a numerical experiment to showcase the impact of diverse parameters on the firm's profits. Given the intricacy of data manipulation, this study employs Mathematica 12.0 for computing the results. Through examples, we demonstrate how different parameters influence the production decisions and profitability of electronic durable goods companies. To initiate the experiment, certain initial values are assigned to the variables. It's imperative that these

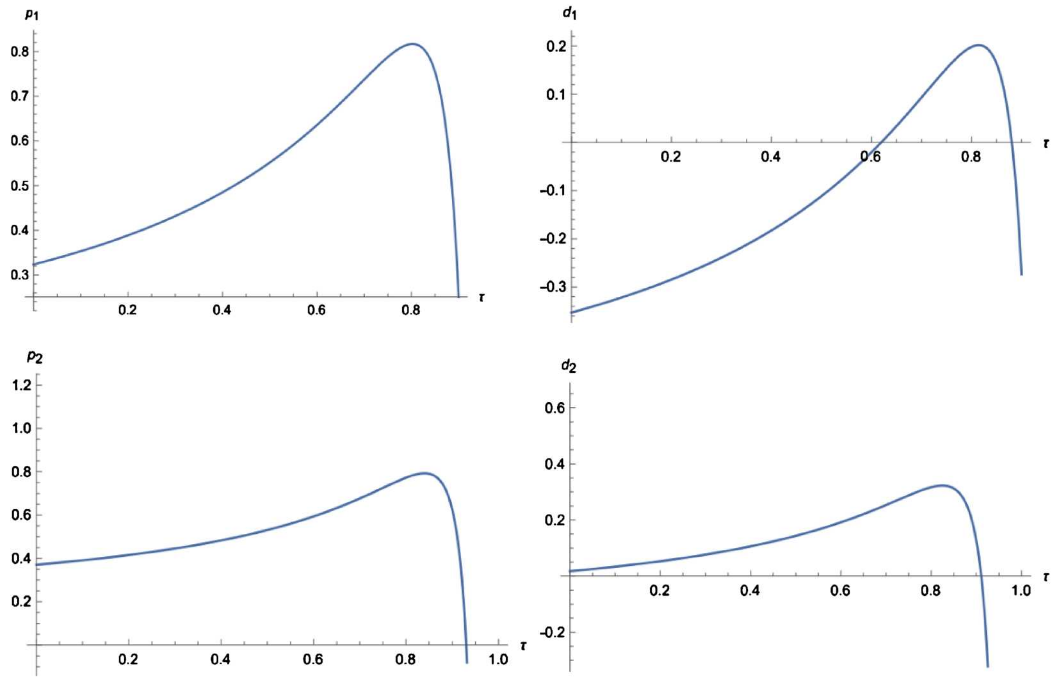

Figure 2. The effect of parameter τ on decision variables.

values adhere to the condition where p_i, d_i, $\beta_i > 0$ and τ, $\delta \in [0, 1]$.

$$\tau = 0.7, \delta = 0.9, \beta_1 = 1.1, \ \beta_2 = 1.2.$$

We then analyze the influence of key parameter, discount rate τ, on the decision variables specifically. As depicted in Figure 2, the impact of the discount rate τ on decision variables unfolds as a dynamic process, rather than exhibiting a straightforward monotonic trend. With the escalation of the discount rate τ, the optimal price and durability of both products follow a pattern of initial ascent followed by a subsequent decline. The visual representation underscores that the maximum values of optimal price and durability are achieved when the discount rate τ approaches approximately 0.8.

Then, we observe how the optimal profits of a company change with parameters. As can be seen from Figure 3, when other parameters remain unchanged, the float of discount level shows a dynamic change to the overall revenue. When τ is larger, it means that the company offers fewer

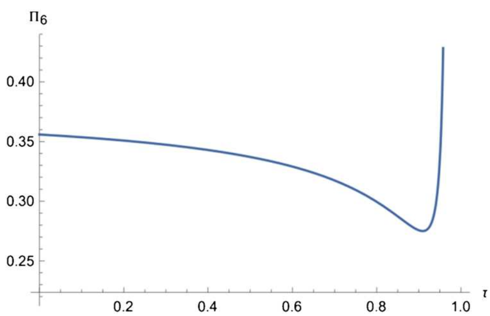

Figure 3. The effect of parameters τ on optimal profits.

discounts to consumers on the old products, which cannot attract consumers to purchase at this time. Therefore, consumer demand can be increased by lowering the price of old products.

5. Conclusions and implications

5.1. Conclusions

In this research, we leverage the common practice among manufacturers in the electronic durable goods sector, where they frequently disclose information about upcoming new-generation products before official press announcements. This aspect is often disregarded in existing literature, despite its significant impact on consumer purchasing behavior. Approaching the study from the perspective of strategic consumer decision-making, we have formulated an optimization model to investigate the durability of new-generation products and the pricing strategy for the preceding generation. Different from the existing literature, this investigation is conducted within the short interim periods between the successive launches of two product generations, considering the preferences of strategic consumers. To address this optimization challenge, we employ a mathematical model, enabling us to derive optimal pricing strategies and determine the ideal durability levels for both product generations.

The study has yielded significant conclusions. Firstly, we have identified optimal pricing and durability values for both generations, denoted as p_1^*, p_2^*, d_1^*, d_2^*. Consequently, we derive the optimal profit, Π_6. Our findings underscore critical considerations that manufacturers must contemplate when deciding on pricing and durability for successive product generations, particularly when dealing with strategic consumers. Secondly, we note the substantial influence of the price discount (τ) on these decision variables. As depicted in Figure 2, the impact of τ on the four variables is non-monotonous, with a specific value of τ (around 0.8 in the case discussed in section 4.2) where all four variables simultaneously reach their maximum values. However, it's noteworthy that at this juncture, the profit is not maximized. Hence, manufacturers must carefully balance considerations of pricing and durability for both generations, and discounts of older generation products to optimize their outcomes.

5.2. Implications

The implications of this paper extend beyond its theoretical framework, offering valuable insights with practical significance for manufacturers in the realm of electronic durable goods. Here are the key implications derived from the study:

The first implication delves into the realm of optimal decision-making for manufacturers, shedding light on the strategic choices available in a monopoly scenario. The conclusions of the paper provide manufacturers with a systematic approach to optimizing pricing and durability decisions for successive product generations in the presence of strategic consumers. The findings underscore the significance of incremental innovation and the implications of information disclosure pertaining to next-generation products. This insight not only holds practical implications for manufacturers but also contributes to theoretical frameworks in the field.

The second implication revolves around the impact of price discount (τ) on consumer behavior and market dynamics. By exploring the consequences of varying price structures, the research enriches our comprehension of how pricing strategies influence consumer choices. As depicted in Figure 3, applying discounts to older generation products can yield some profit increase, but the effect is not substantial. Interestingly, there exists an inflection point close to $\tau = 1$, which corresponds to the absence of price discounts. Under equal conditions, the closer τ approaches 1, the greater the profit. This suggests that refraining from discounting the older generation products can be more profitable. This insight has practical implications for manufacturers aiming to optimize their pricing models and navigate the competitive landscape.

Table 2. Release timelines and initial prices of apple smartphones across previous generations.

Year	2010	2011	2012	2013	2014
Modle	iPhone 4	iPhone 4S	iPhone 5	iPhone 5S	iPhone 6
Price	$649	$649	$649	$649	$649
Year	2015	2016	2017	2018	2019
Modle	iPhone 6S	iPhone 7	iPhone 8	iPhone XR	iPhone 11
Price	$649	$649	$699	$749	$699
Year	2020	2021	2022	2023	
Modle	iPhone 12	iPhone 13	iPhone 14	iPhone 15	
Price	$749	$799	$799	$799	

This observation is consistent with the relatively steady pricing strategies employed by companies such as Apple, particularly in their mobile phones, and Huawei, in their tablet computers, among others. Table 2 illustrates the initial prices of Apple iPhones across various generations. Despite continuous enhancements since the iPhone 4's introduction in 2010, prices remained unchanged until the debut of the iPhone 7 in 2016. Subsequently, there have been minor fluctuations in product prices, with the starting prices of recently released models consistently set at $799 over the last three years (Figure 4).

In December 2023, three months after the launch of the Apple 15, a search on the U.S. electronics retail website BESTBUY for the preceding model, the Apple 14, revealed a price of $729. Despite the introduction of the new generation product, there was no significant price reduction. Similarly, when investigating the Apple 13, its price remained at $629 without experiencing a notable decrease. This underscores the relatively stable pricing of Apple smartphones.

This stability serves as a deterrent against waiting behaviors among strategic consumers who might be attracted to deeply discounted older-generation products, potentially delaying their purchases until they perceive better value in the new generation. Such a scenario has the potential to impact the sales of the newer generation products. Therefore, these companies have strategically

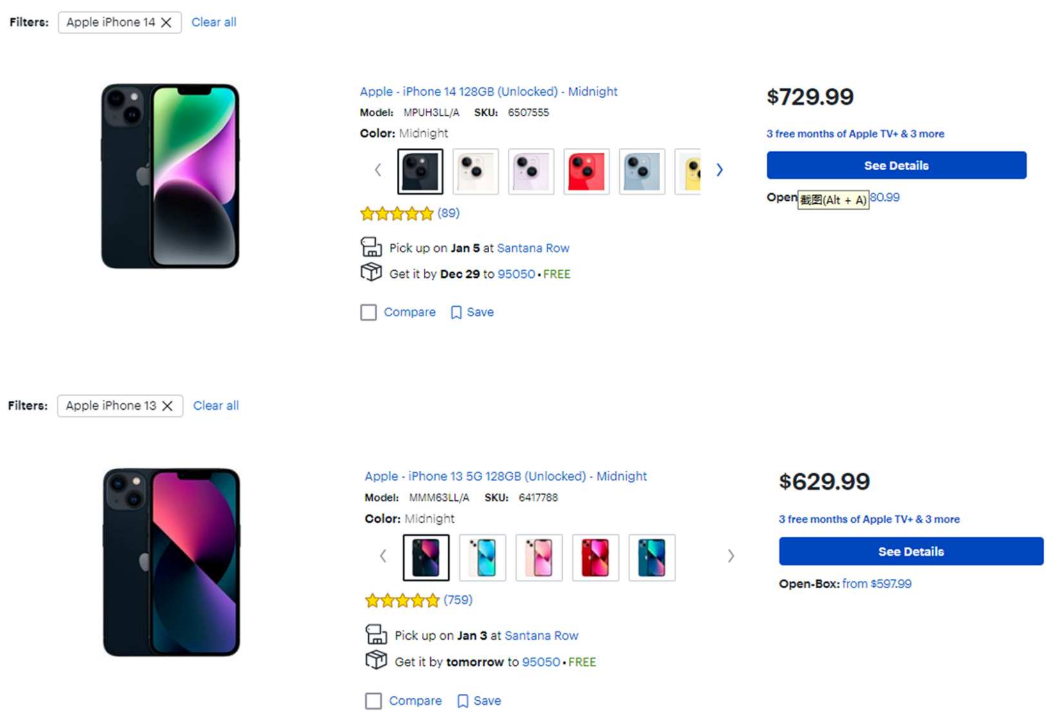

Figure 4. Search results for Apple smartphones on the e-commerce retailer Best Buy.

minimized price volatility to discourage consumers from holding off on purchases and redirecting them towards older product iterations.

It is essential to acknowledge certain limitations in this study. The aforementioned insights are confined to a monopoly scenario, and the concept of waiting costs for strategic consumers delaying their purchasing decisions has not been incorporated. Additionally, the focus has been solely on a single electronic durable goods manufacturer. Future extensions of this research could encompass competitive markets, offering a broader perspective on the subject.

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