On the Interdependence of Strategic Inventories and New Product Generation Introduction

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Abstract

The seminal study by Anand et al. (2008) demonstrates that retailers have an incentive to strategically stock inventories as bargaining chips against upstream manufacturers. To counteract the impact of such strategic inventories, the manufacturer may wish to adjust or introduce products of different qualities in the second period. Shall he then upgrade or downgrade the product's quality? In our model, the manufacturer produces a single product of a given quality in the first period, and the retailer may carry strategic inventories. In the second period, the manufacturer may choose to produce only the existing product, replace it with a new version, or may choose to produce both generations of products. We find that in the absence of strategic inventories, as the quality of the existing product increases, the manufacturer transitions from offering the existing product along with an upgraded generation to offering a downgraded generation next to the existing one, and ultimately offering only the existing version. However, in the presence of strategic inventories, we uncover a new domain: if the quality of the existing product is low, the manufacturer should offer only the upgraded product. In such a scenario, strategic inventories can benefit the manufacturer and retailer as it weakens the magnitude of double marginalization. The volume of strategic inventories decreases in the existing product quality until the retailer carries a sufficiently high volume such that only the upgraded product is offered by the manufacturer because of the retailer's ability to price discriminate between consumers based on their preferences for the two product generations.

Keywords: Supply chain management; Strategic inventories; New generation product; Product quality.

1 Introduction

Introducing a newer generation of products is a key strategic decision, particularly in rapidly changing business environments (Anton and Biglaiser 2013; Shi and Shen 2019). Firms are continuously challenged by fundamental decisions, namely whether, when, and what quality to set for a new generation of products. Examples of such sequential improvements include smartphones, in which the newer generation is often equipped with improved battery performance, contextual intelligence systems, cameras, and recyclable materials.[1] When introducing upgraded versions, car manufacturers have introduced new devices for lane-keeping assistance, automatic emergency braking, smartphone integration, and so forth. For instance, the Toyota Camry line consists of sub models (CE, LE, TRD, XLE, and XSE) reflecting different quality points labeled 'new', 'improved', or 'better'. Similar measures are practiced in household appliances and consumer electronics products, where firms integrate features, such as energy-saving technologies or recyclable materials. For instance, Williams Sonoma had a \$ 275 bread maker in its catalog and later introduced a similar bread maker of marginally higher quality for \$ 429 alongside the existing product.[2] The introduction of downgraded products is also practiced. For example, the luxury automaker Mercedes-Benz introduced an entry-level CLA class in 2013 and subsequent product generations (Li 2019).

If we consider a specific example, Apple has implemented different strategies when new models are introduced over the years. Most of the time, it introduced upgraded products; sometimes, it chooses to stop the production of the existing generation, while at other times, it chooses to continue production for several months. For example, Apple continued to sell the iPhone 12 during the second half of 2021, even though the iPhone 13 was already in the market. In another instance, Apple discontinued the production of the iPhone 6 and 6 Plus models in

[1] For example Samsung's Galaxy A Series. https://www.samsung.com/my/smartphones/galaxy-a-series/?product1=sm-a725fzkhxme&product2=sm-a526blvhxme&product3=sm-a326blvhxme. Accessed on May 20, 2023

[2] www.wsj.com/articles/BL-232B-784. Accessed on May 02, 2023.

2016 when the iPhone 7 was introduced. However, it continued to offer its iPhone XR model when the iPhone 11 and iPhone SE were introduced. Furthermore, Apple introduced newer models of lower quality; for example, Apple introduced the first-generation iPhone SE in 2016 to expand its product lines to the lower end.[3]

When introducing a new product version, the first challenge from the manufacturer's perspective is to offer only an upgraded version or both generations (existing with an upgraded or downgraded version) simultaneously. The second challenge manufacturers face is blending consumer perspectives on quality and price. A survey conducted by Nielsen (2014) on more than 12,000 consumer products introduced across Europe between 2011 and 2013 reported that 76% of these products were discontinued within a year of their introduction. Cannibalization is one reason for product discontinuation, as existing products may serve as (partial) substitutes for upgraded or downgraded products (Erhun et al. 2007). Therefore, when introducing a new version, the manufacturer must balance the substitution effect between two generations. Setting the quality of the new generation sufficiently high or low, and hence the differentiation between the qualities of the two products, can affect the potential for price discrimination. Therefore, the price–quality trade-off between products is critical.

In a multi-period environment, the inventories carried by the retailer affect the interaction between the manufacturer and the retailer. Recent studies (e.g., Anand et al. 2008; Hartwig et al. 2015; Mantin and Jiang 2017; Li et al. 2022b; Elahi et al. 2023) have highlighted the influence of such strategic inventories carried by retailers, as they serve as an instrument by the retailer to solicit a lower second-period wholesale price with other broad-reaching consequences. However, existing studies ignore the effect of the introduction of new generations (Anand et al. 2008; Roy et al. 2019; Saha et al. 2021); if the retailer retains too much inventory of an earlier version, this might considerably affect the profits of both supply chain members. For instance, if the quality difference is low, a low price can indicate either good value or low quality, which might cannibalize the sales of both products (Simonson et al. 1993).

This study aims to support decisions regarding the introduction of newer product generations, upgraded or downgraded, and the respective qualities and wholesale prices while considering the retailer's option to carry inventories. Furthermore, we seek to identify the conditions that result from offering either an existing product only, an upgraded version only, or a combination of existing and upgraded or downgraded versions. The specific settings related to our model are similar to those of Chen et al. (2022) and Liu et al. (2023),where the authors conducted an interview with a GAC Honda salesman in Wuhan city and found that a high level of inventory induces the manufacturer (car company) to offer a lower wholesale price. In addition, the manufacturer (Honda) also regularly introduces new versions with various features and

[3]https://en.wikipedia.org/wiki/Template:Timeline_of_iPhone_models. Accessed on Dec 20, 2022.

functionalities.[4] On the contrary, a markdown strategy is also an effective way for several automobile manufacturers to capture their market share. To minimize costs, manufacturers opt to degrade or even remove specific features. For example, General Motors (GM) China reduced the price of a Buick LaCrosse sedan with a 2.0-liter displacement and turbocharged engine, while the rear brake changed from a vented disc brake to a disc brake.[5]

Therefore, our setting relates to the product line extension problem, which has been studied from operational, financial, and marketing perspectives (Hua et al. 2011; Gao et al. 2020). Manufacturers use line extension strategies to increase their brand exposure and attract a wider variety of consumers, which helps increase their market share and sale (Smith and Park 1992). Consistent with the literature, we model this multi-period decision scenario by assuming a supply chain consisting of one manufacturer and one retailer, where the upstream manufacturer can introduce upgraded (Heath et al. 2011; Kahn 2018) or downgraded (Amaldoss and Shin 2011; Hou et al. 2020) products in the second period.

In this two-period supply chain setting, we assume that the manufacturer acts as a Stackelberg leader. Accounting for the retailer's strategic inventory decision, we explore whether strategic inventories encourage or discourage the manufacturer from introducing a new generation of products, and whether the manufacturer offers both generations if it introduces a new generation. We derive analytical solutions by solving the model backward to reach a subgame-perfect Nash equilibrium. A detailed discussion on the effects of these parameters on profit and product quality provides a comprehensive overview of the marketing and operational aspects that supply chain managers must consider.

Our theoretical model captures the effect of inventory for an earlier product version in the sequential introduction of quality-improving or quality-degrading products and dynamic pricing decisions. The key contributions of this study are as follows.

1. We fully characterize the equilibrium strategies employed by the two players in the presence of strategic inventory. Our analysis demonstrates that the retailer's strategic inventory decision influences the introduction of upgraded or downgraded products. To the best of our knowledge, this is the first study to explore when a manufacturer shall introduce upgraded or downgraded products or abstain from introducing a newer version in a two-period supply chain setting. Solutions, explicit thresholds for the model parameters, and comparative evaluations can benefit managers in understanding the dynamics and corresponding pricing strategies. For instance, although the upgraded product attracts more consumers with quality preferences, profits might decrease due to the high per-unit cost for two generations of high-quality products.

[4] https://en.wikipedia.org/wiki/List_of_Honda_automobiles. Accessed on Jan 20, 2023.

[5] http://news.4hw.com.cn/qiche/20141125/31912.html. Accessed on Nov 02, 2023.

2. This study also contributes to the product line literature by supporting how another source of the product in the current period (strategic inventories) impacts the upgraded or downgraded unit sales through product line cannibalization. Our analysis clearly identifies the conditions under which a manufacturer should introduce an upgraded or a downgraded version and continue with the existing product. If the manufacturer discontinues the earlier version, the retailer's strategic inventories can ensure the coexistence of two generations in the second period. However, the manufacturer charges a higher wholesale price for the existing product in the first period. The use of strategic inventories allows the manufacturer and the retailer to profit more, mitigating the double marginalization in the supply chain.

3. Finally, grounded in a two-period supply chain setting, our study shows that manufacturers may fall into a "Prisoner's Dilemma." Suppose a manufacturer invests in quality change and introduces a new version, with or without continuing the earlier version. In this case, stopping the offering of an earlier version can be catastrophic, especially when only an upgraded product of higher quality is introduced. In that scenario, strategic inventories may offer a way out of the "Prisoner's Dilemma," leading to positive economic impacts for both members, which helps segment the market.

2 Literature review

This study primarily relates to two streams of literature: pricing decisions in a product line and retailers' strategic inventories. We discuss each of these below.

2.1 Pricing decision in a product line

Manufacturers often offer differentiated product quality characteristics, such as flavor (e.g., yogurt and soft drinks) or color (e.g., mobile phones). Releasing a new version of a product allows manufacturers to satisfy a wide range of customers. Earlier works by Katz (1984) and Moorthy (1984) explored the pricing strategy of a manufacturer selling quality-differentiated products directly to consumers. Villas-Boas (1998), Liu and Cui (2010), Hua et al. (2011), and Hsiao et al. (2019) discussed the product line design problem in which a manufacturer provides a product line through a retailer. Draganska and Jain (2006) analyzed pricing strategies for manufacturers across product lines and concluded that manufacturers might use product lines as price discrimination tools. Some studies have explored pricing and quality change investment decisions when a manufacturer sells two different types of products in a single-period supply chain setting but have ignored the effect of the retailer's strategic decisions. Cohen-Vernik and Purohit (2014) studied a two-period model in which a single manufacturer sells two products through two retailers and found that the presence of both could affect order quantities. Ma and Mallik (2017) considered a single manufacturer that produces two vertically differentiated products (basic and premium) through a single retailer and found that offering both products is not an equilibrium outcome under zero production costs. As reported by Dong and Liu (2021), product-line pricing can be beneficial if products are substitutable or complementary when the manufacturer acts as a Stackelberg leader. Furthermore, some scholars have focused on the competition between two chains, that is, two manufacturers that produce products of two different qualities (e.g., Wu 2013; Liu et al. 2018; Xia et al. 2022; Zhang et al. 2023).

Research has also explored the characteristics of a supply chain model in which members trade with quality-differentiated products (Zhou et al. 2015; Thies et al. 2019; Gupta et al. 2021; Xiao et al. 2023). Barbarossa and De Pelsmacker (2016) empirically studied how consumer attitudes, purchasing intentions, and behaviors affect product selection. Tsai et al. (2013) proposed mathematical programming to incorporate capacity expansion to maximize the profits of a green product line. Shen et al. (2020) considered a price- and quality-dependent model for green and non-green products and found that if the product quality difference is high, then selling green products is beneficial not only in terms of profit but also from an environmental perspective. De Giovanni and Zaccour (2022) provide a recent review of the impact of quality on supply chain decisions. The key contribution of the present study to this stream of literature is that these prior studies have yet to explore the impact of inventories carried by downstream retailers. Furthermore, researchers have either formulated models under a single-period setting or assumed that the manufacturer offers both products. Therefore, the existence of earlier generations of products as strategic inventories was ignored.

2.2 Retailer's strategic inventories

Anand et al. (2008)'s seminal study on strategic inventories initiated a literature stream exploring retailers' incentives to hold on to inventories as a strategic chip in a multi-period bilateral setting. Along with Anand et al. (2008), Keskinocak et al. (2008) and Hartwig et al. (2015) have shown that a retailer might strategically hold inventory to weaken manufacturers' pricing power in a later period. Desai et al. (2010) extended this setting to allow for horizontal competition among retailers, demonstrating that manufacturers can also benefit from retailers' strategic inventories. Arya and Mittendorf (2013) found that direct consumer rebates introduced by the manufacturer can encourage retailers to alleviate the volume of their strategic inventories and thus increase the expected profit of each supply chain member. Mantin and Jiang (2017) found that for quality-deteriorating products, the retailer's decision to retain inventory can ensure benefits for all supply chain members. However, the retailer does not maintain inventory under the manufacturer's wholesale price commitment. Moon et al. (2018) studied how investment decisions to enhance market demand change if the retailer retains inventory. They found that, in equilibrium, the volume of inventory is reduced in the manufacturer's investment. Roy et al. (2019) found that strategic inventories exist even if the manufacturer has no foresight (asymmetric information) regarding how much inventory the retailer retains. The authors showed that regardless of whether the manufacturer offers commitment or dynamic contracts, the retailer's optimal strategy is to retain inventory.

Mantin and Veldman (2019) found that strategic inventories largely affect manufacturers' cost-reducing process improvement decisions. Even if the holding cost is sufficiently high, process improvement investments ensure that both the supplier and retailer are better off in the presence of inventories. Guan et al. (2019) explored the optimal decision of when products are sold directly to customers as well as through retailers and found that by carrying strategic inventories, a retailer can be more competitive in the presence of a direct channel. Wang et al. (2022) studied the effects of strategic inventories on socially responsible dual distribution channels. The authors found that the retailer can benefit from carrying strategic inventories, but the manufacturer can prevent the retailer from carrying inventories by improving efficiency in the direct channel. Chen et al. (2022) studied the effects of strategic inventories and rebates on customers under supply chain competition. The authors found that both retailers should carry inventories for their respective benefits, but manufacturers are better off if competition intensity is sufficiently low. Additional contexts involving the influence of strategic inventories have also been explored by Dey et al. (2019), Saha et al. (2021), Li et al. (2021), Roy et al. (2022), Elahi et al. (2023), and Liu et al. (2023). The studies mentioned above do not examine the interaction between the decisions to introduce a new version or stop offering an existing version; simultaneously, the downstream retailer may retain inventory of the existing version. Therefore, our work differs from these studies as we examine scenarios where the manufacturer may introduce an upgraded or downgraded product in the second period. We explore how strategic inventory influences manufacturers' wholesale pricing decisions.

3 Model Description

To study the impact of strategic inventories on product introduction, we developed a two-period non-cooperative bilateral game-theoretic model consisting of an upstream manufacturer, denoted by M, and a downstream retailer, denoted by R (Anand et al. 2008; Mantin and Veldman 2019; Liu et al. 2023). In the first period ($t = 1$), the manufacturer produces only the existing product, denoted by the subscript e. The manufacturer sets the wholesale price of the product,

w_{1e}, and then the retailer decides the order quantity, Q_{1e},which is composed of the units they plan to sell in the first period, q_{1e}, and the units that are carried over to the second period, $I = Q_{1e} - q_{1e} \geq 0$, and sets the retail price, p_{1e} for the first period.

In the second period ($t = 2$), the manufacturer may introduce a partially substitutable upgraded or downgraded version, denoted by the subscripts u and d, respectively. Following Wheelwright and Clark (1992) and Trott (2008), we assume that the manufacturer may sell the new version along with the earlier version. Thus, the manufacturer may wholesale both products (existing with either an upgraded or a downgraded version), only the existing product, or only an upgraded version. Given the manufacturer's product portfolio decision, the retailer then orders $Q_{2e} = q_{2e} - I$ units of the existing product and $Q_k = q_k,\ k \in \{u, d\}$, units of the newer version; and sets the retail prices, $p_{2k},\ k \in \{e, u, d\}$.

We assume the quality of the existing product is θ_e, and that of the newer product is $\theta_k,\ k \in \{u, d\}$. As in Liu and Zhang (2013), Lin et al. (2020), and Wu et al. (2022), the authors assume the qualities of the product as given exogenously. The authors primarily focused on pricing decisions in different supply chain contexts, ignoring the effects of strategic inventory. In this study, we assume that the manufacturer determines the quality of the new version relative to the existing version. For analytical tractability, we normalize $\theta_e = \theta$ and set $\theta_u = \delta_u\theta$ with $\delta_u > 1$,to reflect the upgraded product quality relative to that of the existing product. Similarly, $\theta_d = \delta_d\theta$ with $\delta_d < 1$ is the quality level of the downgraded product relative to that of the existing product. Consistent with prior literature, we assume that the cost of producing one unit of a product with quality θ_k is $\eta\theta_k^2$ ($k \in \{e, u, d\}$), where $\eta > 0$ can be interpreted as a quality cost factor (Dey et al. 2019). We further assume that the end consumers are neither strategic nor forward-looking.

To represent the demand function, we assume consumers' utility as $U_{tk} = v\theta_k - p_{tk}$ ($t = 1, 2$; $k = e, u, d$), where v represents the consumers' valuation of product generations (willingness to pay), uniformly distributed on $[0, 1]$ (e.g., Mantin and Jiang 2017 and Li et al. 2022a). Therefore, consumers make purchase decisions based on retail prices (p_k) and qualities (θ_k) provided by the manufacturer. Each consumer purchases at most one unit of the product that provides the greatest utility as long as it is strictly positive or nothing at all if none provides a positive utility. Similar to Mantin and Jiang (2017), the first-period indifferent customers between buying the existing product and not buying it ($v_{1e} = \frac{p_{1e}}{\theta}$) is obtained by solving $U_{1e} = v\theta - p_{1e} = 0$. Accordingly, the demand for the existing product in the first period is

$$q_{1e}(p_{1e}) = 1 - \frac{p_{1e}}{\theta} \tag{1}$$

Suppose the manufacturer offers an upgraded product with the earlier version in the second period. Then, the indifference consumers between buying an existing or upgraded product (v_{ue}), between buying an existing product or not buying at all (v_{2e}), and between buying an upgraded product or not buying (v_u), are obtained by solving $U_u = U_{2e}$, $U_{2e} = 0$, and $U_u = 0$, respectively. These results with $v_{ue} = \frac{p_u - p_{2e}}{(\delta_u - 1)\theta}$, $v_{2e} = \frac{p_{2e}}{\theta}$, and $v_u = \frac{p_u}{\delta_u \theta}$, respectively. Thus, in the second period, the interaction between consumers who would prefer to buy the upgraded product over the existing product and the existing product over the upgraded product can be found if the valuations are in $[v_{ue}, 1]$ and $[v_e, v_{ue}]$, respectively. Therefore, the demands for the existing (q_{2e}) and the upgraded (q_u) products when both products are sold are as follows:

$$\left.\begin{aligned} q_{2e}(p_{2e}, p_u, \delta_u) &= \frac{p_u - \delta_u p_{2e}}{(\delta_u - 1)\theta} \\ q_u(p_{2e}, p_u, \delta_u) &= 1 - \frac{p_u - p_{2e}}{(\delta_u - 1)\theta} \end{aligned}\right\} \tag{2}$$

Similarly, suppose the manufacturer introduces downgraded products; in that case, the demands for the existing (q_{2e}) and the downgraded (q_d) products when both products are sold are as follows:

$$\left.\begin{aligned} q_{2e}(p_{2e}, p_d, \delta_d) &= 1 - \frac{\delta_d p_{2e} - p_d}{(1 - \delta_d)\theta} \\ q_d(p_{2e}, p_d, \delta_d) &= \frac{p_d - \delta_d p_{2e}}{(1 - \delta_d)\delta_d \theta} \end{aligned}\right\} \tag{3}$$

From Equations (2) and (3), we note that the demand for product k, $k \in \{e, u, d\}$ in the second period decreases with its price and increases as the price of the alternative product increases. When only the existing product or an upgraded generation is offered in the second period, the demand functions are given by:

$$q_{2e}(p_{2e}) = 1 - \frac{p_{2e}}{\theta} \tag{4}$$

$$q_u(p_u, \delta) = 1 - \frac{p_u}{\delta_u \theta} \tag{5}$$

To facilitate analysis, we impose the following mild assumption. The quality change investment cost coefficient satisfies $\eta\theta < 1$, which states that demand volume is positive (i.e., $q_{tk} > 0$), and both the manufacturer and the retailer receive benefits (i.e., $p_{tk} > w_{tk}$ and $w_{tk} > \eta\theta_k^2$) from the per unit product transaction. Similar to the literature that explores the influence of strategic inventories in multi-period bilateral supply chains, we normalize the unit marginal cost of the retailer to zero. The supply chain members have symmetric information about cost and demand parameters (as in Anand et al. 2008, Arya et al. 2015, Saha et al. 2021, and Liu et al. 2023). Since the manufacturer may offer two products or only one in the second period and the retailer may or may not hold inventories strategically, this gives rise to the following scenarios:

- The manufacturer offers two products in the second period: the existing version (E) along with either the upgraded (U) or downgraded (D) versions. The retailer either carries (I) or does not carry (N) strategic inventories of the existing products (Scenarios EUI/EUN/EDI/EDN).

- The manufacturer offers only one product in the second period: the existing (E) or upgraded (U) product, and the retailer carries (I) or does not carry (N) strategic inventories for the existing products (Scenarios EI/EN/UI/UN). As an extension, we also explore the scenario where the manufacturer introduces only a downgraded version, which we call Scenarios DI and DN (Golder et al. 2018; Li et al. 2016; Giannakas and Fulton 2011). We present all the major results with those two options in Appendix F.

The profit maximization problems when both an existing and a new product, either upgraded or downgraded, are offered, i.e., Scenario EUI or EDI, are as follows ($k = d, u$):

$$\pi_m(w_{1e}) = (w_{1e} - \eta\theta^2)(q_{1e} + I) + \pi_{m2}(w_{2e}, w_k, \delta_k) \tag{6}$$

$$\pi_r(q_{1e}, I) = q_{1e}p_{1e} - w_{1e}(q_{1e} + I) - hI + \pi_{r2}(q_{2e}, q_k) \tag{7}$$

$$\pi_{m2}(w_{2e}, w_k, \delta_k) = (w_{2e} - \eta\theta^2)(q_{2e} - I) + q_k(w_k - \eta{\delta_k}^2\theta^2) \tag{8}$$

$$\pi_{r2}(q_{2e}, q_k) = q_{2e}p_{2e} - w_{2e}(q_{2e} - I) + q_k(p_k - w_k) \tag{9}$$

By substituting $I = 0$, in Equations (6)- (9), we obtain the profit functions in Scenarios EUN and EDN. In addition, we present profit functions for the retailer and manufacturer when the manufacturer sells only the existing product (left column) or only the upgraded product (right column) in the following Table 1.

Table 1: Profit functions for the manufacturer and retailer in Scenarios EI and UI

Only an existing product	Only an upgraded product
$\pi_m(w_{1e}) = (w_{1e} - \eta\theta^2)(q_{1e} + I) + \pi_{m2}(w_{2e})$	$\pi_m(w_{1e}) = (w_{1e} - \eta\theta^2)(q_{1e} + I) + \pi_{m2}(w_u, \delta_u)$
$\pi_r(q_{1e}, I) = q_{1e}p_{1e} - w_{1e}(q_{1e} + I) - hI + \pi_{r2}(q_{2e})$	$\pi_r(q_{1e}, I) = q_{1e}p_{1e} - w_{1e}(q_{1e} + I) - hI + \pi_{r2}(I, q_u)$
$\pi_{m2}(w_{2e}) = (w_{2e} - \eta\theta^2)(q_{2e} - I)$	$\pi_{m2}(w_u, \delta_u) = q_u(w_u - \eta{\delta_u}^2\theta^2)$
$\pi_{r2}(q_{2e}) = q_{2e}p_{2e} - w_{2e}(q_{2e} - I)$	$\pi_{r2}(I, q_u) = Ip_{2e} + q_u(p_u - w_u)$

Note: If $I = 0$, we obtain the profit functions in Scenarios EN and UN

For clarity, all subscripts, superscripts, decision variables, and model parameters are listed in Table 2.

Table 2: **Summary of notations**

Symbol	Description
Subscript	
t	Selling period, $t = 1, 2$
k	Product type, $k \in \{e, u, d\}$
i	Supply chain member, $i \in \{m, r\}$
Superscript	
s	Scenario, $s \in \{EUI, EDI, EUN, EDN, EI, UI, EN, UN\}$
Decision Variable	
w^s_{tk}	Wholesale price of product k in period t under scenario s
I^s	Strategic inventory level of the existing product under scenario s
p^s_{tk}	Selling price of product k in period t under scenario s
Q^s_{tk}	Order quantity of product k in period t under scenario s
q^s_{tk}	Demand of product k in period t under scenario s
δ^s_k	Quality level of the new version relative to that of the existing product
π^s_i	Total profit for i^{th} supply chain member in scenario s
Π^s	Total supply chain profit in scenario s
Parameters	
θ	Quality level of the existing version ($\theta_e = \theta > 0$)
η	Quality cost factor coefficient
h	Per unit holding cost

Notes: time subscript is not required for product type; $k = u, d$, as it may be offered only in the second period.

4 Model analysis

We present the optimal decisions under the non-cooperative game models in the following two subsections. In Subsection 4.1, we present the optimal responses in which the retailer does not retain strategic inventories, followed by Subsection 4.2, where the retailer retains strategic inventories.

4.1 No strategic inventories

In this section, we analyze the scenario in which the retailer does not retain strategic inventories. In Period 1, the upstream manufacturer sets the wholesale price (w_{1e}) for the existing product. Based on this, the retailer determines the order quantity (q_{1e}) and sets the retail price (p_{1e}) accordingly. In Period 2, the manufacturer decides whether to continue offering the earlier version along with a newly introduced upgraded or downgraded version or only the earlier version, or only an upgraded version. Therefore, the manufacturer determines the quality level of the upgraded product ($\theta_u = \delta_u\theta$) or downgraded product ($\theta_d = \delta_d\theta$) as well as wholesale prices. Based on that, the retailer sets retail prices. The timeline of these events is shown in Figure 1.

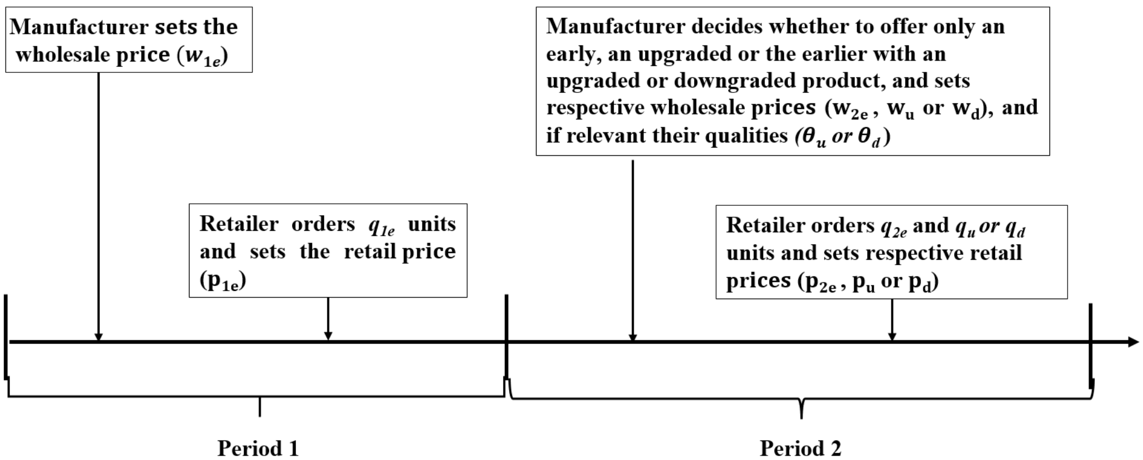


Figure 1: Sequence of events without strategic inventory.

The optimal responses for the members are presented in Table 3. In the online Supplementary S1, we also consider and derive optimal decisions when the manufacturer determines the quality of the new version already in the first period ahead of the inventory decisions. Qualitatively, our results follow through.

Note that in Scenario UN, product quality must be higher compared to the existing version (i.e. $\delta_u^{UN} > 1$) if $\theta < \frac{1}{3\eta}$. From Table 3, we observe that when both the upgraded and existing products are offered, the upgraded product quality is higher than that of the existing product if $\theta < \frac{1}{2\eta}$ ($\theta_u^{EUN} > \theta_e^{EUN}$), and the quantity of the upgraded product (q_u^{EUN}) remains positive in this range. Similarly, when both the downgraded and existing products are offered, the quantity for the existing product (q_{2e}^{EDN}) remains positive if $\theta < \frac{2}{3\eta}$. We have the following lemma to characterize optimal product quality.

Lemma 1 *Given the existing product quality level θ, the quality level of the newly introduced product satisfies the following relations:*

- *If $\theta \in (0, \frac{1}{3\eta})$, the product qualities satisfy $\theta_u^{EUN} \geq \theta_u^{UN} \geq \theta_e^{EN} \geq \theta_d^{EDN}$*
- *If $\theta \in (\frac{1}{3\eta}, \frac{1}{2\eta})$, the product qualities satisfy $\theta_u^{EUN} \geq \theta_e^{EN} \geq \theta_d^{EDN}$*
- *If $\theta \in (\frac{1}{2\eta}, \frac{2}{3\eta})$, the product qualities satisfy $\theta_e^{EN} \geq \theta_d^{EDN}$.*

We explain the existence of such thresholds as follows. First, the manufacturer may fail to compensate the cost of offering two high-quality products if the quality of the existing product

Table 3: Optimal responses in decentralized scenarios when no inventories are carried

	Scenario EUN	Scenario EDN	Scenario EN	Scenario UN
w_{1e}^s	$\frac{(1+\eta\theta)\theta}{2}$	$\frac{(1+\eta\theta)\theta}{2}$	$\frac{(1+\eta\theta)\theta}{2}$	$\frac{(1+\eta\theta)\theta}{2}$
q_{1e}^s	$\frac{1-\eta\theta}{4}$	$\frac{1-\eta\theta}{4}$	$\frac{1-\eta\theta}{4}$	$\frac{1-\eta\theta}{4}$
p_{1e}^s	$\frac{(3+\eta\theta)\theta}{4}$	$\frac{(3+\eta\theta)\theta}{4}$	$\frac{(3+\eta\theta)\theta}{4}$	$\frac{(3+\eta\theta)\theta}{4}$
w_{2e}^s	$\frac{(1+\eta\theta)\theta}{2}$	$\frac{(1+\eta\theta)\theta}{2}$	$\frac{(1+\eta\theta)\theta}{2}$	-
q_{2e}^s	$\frac{1+\eta\theta}{12}$	$\frac{2-3\eta\theta}{8}$	$\frac{1-\eta\theta}{4}$	-
p_{2e}^s	$\frac{(3+\eta\theta)\theta}{4}$	$\frac{(3+\eta\theta)\theta}{4}$	$\frac{(3+\eta\theta)\theta}{4}$	-
w_k^s	$\frac{(1+\eta\theta)(4+\eta\theta)}{18\eta}$	$\frac{(2+\eta\theta)\theta}{8}$	-	$\frac{2}{9\eta}$
q_k^s	$\frac{1-2\eta\theta}{6}$	$\frac{\eta\theta}{4}$	-	$\frac{1}{6}$
p_k^s	$\frac{(1+\eta\theta)(10+\eta\theta)}{36\eta}$	$\frac{\theta(6+\eta\theta)}{16}$	-	$\frac{5}{18\eta}$
δ_k^s	$\frac{1+\eta\theta}{3\eta\theta}$	$\frac{1}{2}$	-	$\frac{1}{3\eta\theta}$
π_r^s	$\frac{(2-\eta\theta)(1+\eta\theta(8-11\eta\theta))}{216\eta}$	$\frac{\theta(8-16\eta\theta+9\eta^2\theta^2)}{64}$	$\frac{(1-\eta\theta)^2\theta}{8}$	$\frac{4+27\eta\theta(1-\eta\theta)^2}{432\eta}$
π_m^s	$\frac{(2-\eta\theta)(1+\eta\theta(8-11\eta\theta))}{108\eta}$	$\frac{\theta(8-16\eta\theta+9\eta^2\theta^2)}{32}$	$\frac{(1-\eta\theta)^2\theta}{4}$	$\frac{4+27\eta\theta(1-\eta\theta)^2}{216\eta}$

is too high. It is clear that the selling quantity of the upgraded product (q_u^{EUN}) decreases with θ, and becomes zero if $\theta = \frac{1}{2\eta}$. Second, the presence of two products with similar qualities may not ensure a quality-differentiating effect on skim profits for manufacturers. Overall, it is also noticeable that only upgraded products can be offered (Scenario UN) if $\theta < \frac{1}{3\eta}$, both upgraded and existing products can be offered (Scenario EUN) if $\theta < \frac{1}{2\eta}$, and only the existing product can be offered (Scenario EN) if $\theta < \frac{1}{\eta}$. Third, if only an upgraded product is offered (Scenario UN), the product quality is not higher than that in Scenario EUN, in which both existing and upgraded products are offered. The results indicate that if two products are offered, the manufacturer must maintain a higher product quality difference. We make the following lemma to characterize the nature of wholesale and retail prices:

Lemma 2 *If strategic inventories are not carried, then,*

1. *the wholesale and retail prices of the existing product in Period 2 are lower (respectively, higher) than the upgraded (respectively, downgraded) product if it is introduced, i.e.,* $w_u^{EUN} > w_{2e}^{EUN}$, $w_{2e}^{EDN} > w_d^{EDN}$, $p_u^{EUN} > p_{2e}^{EUN}$, *and* $p_{2e}^{EDN} > p_d^{EDN}$.

2. *when a new version is offered with the existing product, the wholesale and retail prices increase with earlier version product quality, i.e.,* $\frac{\partial w_u^{EUN}}{\partial\theta} > 0, \frac{\partial w_d^{EDN}}{\partial\theta} > 0, \frac{\partial p_u^{EUN}}{\partial\theta} > 0, \frac{\partial p_d^{EDN}}{\partial\theta} > 0$.

3. *when only an upgraded product is offered, its wholesale and retail prices remain independent of the earlier version product quality.*

See Appendix E for the detailed proof. Table 3, shows that the wholesale and retail prices remain the same in both periods. Therefore, if inventory does not exist, pricing decisions remain independent in both periods, and the introduction of a new generation does not have any impact. Intuitively, the wholesale and retail prices should be high if an upgraded product is to be introduced.

We also derive the optimal decision in the centralized setting (See Appendix A), that is, a firm directly selling products to a customer, and find that the product quality remains identical with non-cooperative game models (See Tables 3 and A.1). Product quality adjustments require changes in both production processes and investments. In addition, adjusting product quality is more challenging than adjusting prices. Quality changes require the development and integration of critical underlying technologies, processes, new materials, and so forth (Erat and Kavadias 2006; Gunasekaran et al. 2019). In the literature and industrial practices, there are many different Key Performance Indicators (KPIs), such as reconfigurability, flexibility, changeability, and co-evolution, which are individually related to quality change (Golder et al. 2018). When a manufacturer changes product quality, all those high-level decisions might not be directly related to the decision of whether a downstream retailer should carry inventories or not. In practice, inventory holding costs for the retailer may also differ and a manufacturer can sell products through multiple retailers, and some of them may not carry inventories. Therefore, we assume that the product quality levels remain the same (as shown in Table 3) even if the retailer retains inventories. Moreover, a manufacturer does not necessarily assume that the retailer holds inventories of an existing version during the product development phase and accordingly adjust quality. This specific restriction delivers the most intuition with much less ex-positional and notational baggage.

4.2 With strategic inventories

This section studies the retailer's quantity and strategic inventory decisions and wholesale pricing decisions for the manufacturer. Similar to (Anand et al. 2008; Arya and Mittendorf 2013; Mantin and Jiang 2017), the decision sequence is defined as follows:

1. In period 1, the manufacturer offers wholesale price (w_{1e}) to the retailer. Based on that the retailer decides on any unit procured ($Q_{1e} = q_{1e} + I,\ I \geq 0$) and those can either be sold in the first period as well as held as strategic inventories, that is, $I = Q_{1e} - q_{1e}$, at a per-unit holding cost h, totaling $h \cdot I$.

2. In period 2, the manufacturer decides whether to continue offering the earlier version along with a newly introduced upgraded or downgraded version, or only the earlier version, or only an upgraded version and keeps the quality level of the new version the same as in the no-inventory scenario. Therefore, the manufacturer sets the wholesale price for the earlier (w_{2e}) or upgraded version (w_u) or downgraded version (w_d). Based on that, the retailer sets retail prices for upgraded (p_u) or downgraded (p_d) and existing products (p_{2e}).

The timeline of these events is presented in Figure 2.

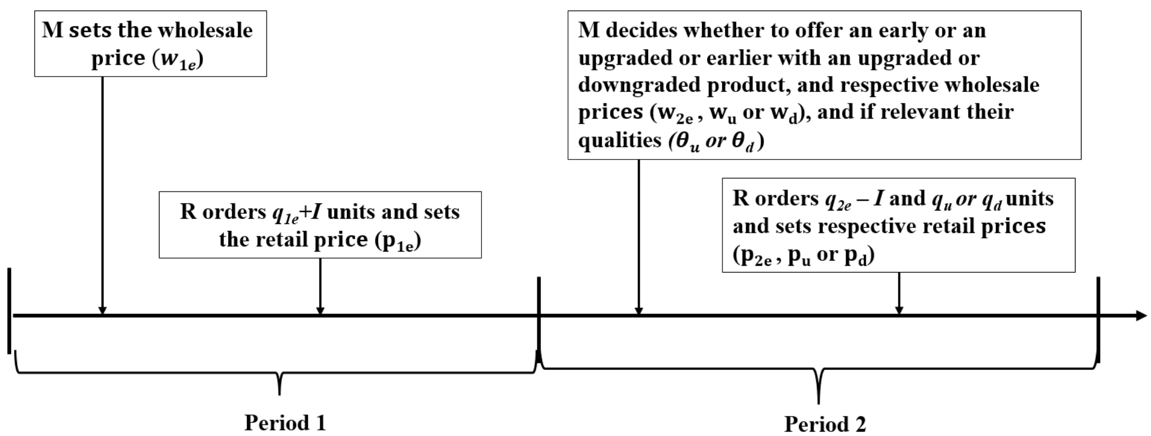


Figure 2: Sequence of events with the strategic inventory.

In Appendix C, we derive the responses for each of the four scenarios and summarize the responses in Table 4.

We make the following lemma to summarize how strategic inventory impacts pricing decisions for an upstream manufacturer and a downstream retailer.

Lemma 3 *If strategic inventories are carried, then*

1. *the wholesale and retail prices of the existing product in Period 1 are always higher compared to Period 2, i.e.,* $w_{1e}^{EUI} \geq w_{2e}^{EUI}$, $p_{1e}^{EUI} \geq p_{2e}^{EUI}$, $w_{1e}^{EDI} \geq w_{2e}^{EDI}$, $p_{1e}^{EDI} \geq p_{2e}^{EDI}$, $w_{1e}^{EI} \geq w_{2e}^{EI}$, $p_{1e}^{EI} \geq p_{2e}^{EI}$

2. *the wholesale and retail prices of the existing product in Period 2 are always lower (respectively, higher) than the upgraded (respectively, downgraded) product if it is introduced, i.e.,* $w_u^{EUI} \geq w_{2e}^{EUI}$, $w_d^{EUI} \geq w_{2e}^{EUI}$, $p_u^{EUI} \geq p_{2e}^{EUI}$, *and* $p_d^{EUI} \geq w_{2e}^{EUI}$

3. *wholesale price and retail price for upgraded (or downgraded) product increase with earlier version product quality if those are offered with the earlier version, i.e.,* $\frac{\partial w_d^{EDI}}{\partial \theta} > 0$, $\frac{\partial w_u^{EUI}}{\partial \theta} > 0$, $\frac{\partial p_d^{EDI}}{\partial \theta} > 0$, $\frac{\partial p_u^{EUI}}{\partial \theta} > 0$.

Table 4: Optimal decisions in decentralized scenarios when inventories are carried

	Scenario EUI	Scenario EDI	Scenario EI	Scenario UI
w_{1e}^s	$\frac{\theta(9+8\eta\theta)-2h}{17}$	$\frac{\theta(9+8\eta\theta)-2h}{17}$	$\frac{\theta(9+8\eta\theta)-2h}{17}$	$\frac{(26\theta-36h)(4-3\eta\theta)-27\eta^2\theta^3(3-\eta\theta)+96h}{6(8(2-3\eta\theta)+(4-3\eta\theta)^2)}$
q_{1e}^s	$\frac{4(1-\eta\theta)\theta+h}{17\theta}$	$\frac{4(1-\eta\theta)\theta+h}{34\theta}$	$\frac{4(1-\eta\theta)\theta+h}{17\theta}$	$\frac{(2-3\eta\theta)(44\theta-3\eta\theta^2(13-3\eta\theta)+36h)-24h}{12\theta(32-3\eta\theta(16-3\eta\theta))}$
p_{1e}^s	$\frac{(13+4\eta\theta)\theta-h}{17}$	$\frac{(13+4\eta\theta)\theta-h}{17}$	$\frac{(13+4\eta\theta)\theta-h}{17}$	$\frac{\theta(296-366\eta\theta)+27\eta\theta(4h-\eta\theta^2+\eta^2\theta^3)-48h}{12(8(2-3\eta\theta)+(4-3\eta\theta)^2)}$
I^s	$\frac{5(1-\eta\theta)\theta-20h}{34\theta}$	$\frac{5(1-\eta\theta)\theta-20h}{34\theta}$	$\frac{5(1-\eta\theta)\theta-20h}{34\theta}$	$\frac{\theta(14-3\eta\theta(10-3\eta\theta))-18h(2-\eta\theta)}{3\theta(8(2-3\eta\theta)+(4-3\eta\theta)^2)}$
w_{2e}^s	$\frac{(6+11\eta\theta)\theta+10h}{17}$	$\frac{(6+11\eta\theta)\theta+10h}{17}$	$\frac{(6+11\eta\theta)\theta+10h}{17}$	-
q_{2e}^s	$\frac{(16+\eta\theta)\theta-30h}{102\theta}$	$\frac{(44-61\eta\theta)\theta-40h}{136\theta}$	$\frac{11(1-\eta\theta)\theta-10h}{34\theta}$	$\frac{\theta(14-3\eta\theta(10-3\eta\theta))-18h(2-\eta\theta)}{3\theta(8(2-3\eta\theta)+(4-3\eta\theta)^2)}$
p_{2e}^s	$\frac{(23+11\eta\theta)\theta+10h}{34}$	$\frac{(23+11\eta\theta)\theta+10h}{34}$	$\frac{(23+11\eta\theta)\theta+10h}{34}$	$\frac{(11\theta+3\eta\theta^2+6h)(2-\eta\theta)(2-3\eta\theta)+30\eta\theta^2(1-\eta\theta)}{2(8(2-3\eta\theta)+(4-3\eta\theta)^2)}$
w_k^s	$\frac{34+(20+31\eta\theta)\eta\theta+90h\eta}{153\eta}$	$\frac{3\theta(8+9\eta\theta)+40h}{136}$	-	$\frac{64+54h\eta(2-\eta\theta)-3\eta\theta(46-9\eta\theta(4-\eta\theta))}{9\eta(8(2-3\eta\theta)+(4-3\eta\theta)^2)}$
q_k^s	$\frac{1-2\eta\theta}{6}$	$\frac{\eta\theta}{4}$	-	$\frac{32+9\eta(2-\eta\theta)(6h-\theta(5-3\eta\theta))}{6(8(2-3\eta\theta)+(4-3\eta\theta)^2)}$
p_k^s	$\frac{85+(71+31\eta\theta)\eta\theta+90h\eta}{306\eta}$	$\frac{(92+27\eta\theta)\theta+40h}{272}$	-	$\frac{160+54h\eta(2-\eta\theta)-3\eta\theta(94-9\eta\theta(5-\eta\theta))}{18\eta(8(2-3\eta\theta)+(4-3\eta\theta)^2)}$
δ_k^s	$\frac{1+\eta\theta}{3\eta\theta}$	$\frac{1}{2}$	-	$\frac{1}{3\eta\theta}$
π_r^s	$\frac{\Psi_1}{31212\eta\theta}$	$\frac{\Psi_3}{544\theta}$	$\frac{304h^2-118h\theta(1-\eta\theta)+155\theta^2(1-\eta\theta)^2}{1156\theta}$	$\frac{\Psi_5}{432\eta\theta(8(2-3\eta\theta)+(4-3\eta\theta)^2)^2}$
π_m^s	$\frac{\Psi_2}{918\eta\theta}$	$\frac{\Psi_4}{544\theta}$	$\frac{8h^2-4h\theta(1-\eta\theta)+9\theta^2(1-\eta\theta)^2}{34\theta}$	$\frac{\Psi_6}{216\eta\theta(8(2-3\eta\theta)+(4-3\eta\theta)^2)}$

where $\Psi_1 = \eta(8208h^2 + 2451\theta^2(1-2\eta\theta) - 3186h\theta(1-\eta\theta)) + \theta(289 + 1873\eta^3\theta^3)$; $\Psi_2 = 3\eta(72h^2 + 47\theta^2(1-2\eta\theta) - 36h\theta(1-\eta\theta)) + \theta(17+107\eta^3\theta^3)$; $\Psi_3 = 128h^2 - 64h\theta(1-\eta\theta) + \theta^2(144-\eta\theta(288-161\eta\theta))$; $\Psi_4 = 4864h^2 - 1888h\theta(1-\eta\theta) + \theta^2(2480-\eta\theta(4960-2769\eta\theta))$; $\Psi_5 = \theta(4096 + 20352\eta\theta - 146736\eta^2\theta^2 + 285660\eta^3\theta^3 - 251424\eta^4\theta^4 + 112023\eta^5\theta^5 - 24786\eta^6\theta^6 + 2187\eta^7\theta^7) - 72\eta\theta(320 - 648\eta\theta + 54\eta^2\theta^2 + 243\eta^3\theta^3 - 81\eta^4\theta^4)h + 432\eta(20 - 3\eta\theta)(8 - 15\eta\theta + 9\eta^2\theta^2)h^2$; $\Psi_6 = 432h^2\eta(1+3\eta\theta) - 72h\eta\theta(10 - 3\eta\theta(5+3\eta\theta)) + \theta(128 + 3\eta\theta(292 - 9\eta\theta(7-3\eta\theta)(20 - 15\eta\theta + 3\eta^2\theta^2)))$.

4. *when only an upgraded product is offered, the wholesale and retail price increase with existing product quality, i.e.,* $\frac{dw_u^{UI}}{d\theta} = 2\frac{dp_u^{UI}}{d\theta} > 0$ *if* $h < \hat{h}$, *where* $\hat{h} = \frac{448-3\eta\theta(640-726\eta\theta+288\eta^2\theta^2-27\eta^3\theta^3)}{18\eta(64-36\eta\theta+9\eta^2\theta^2)}$.

See Appendix E for the detailed proof. At a glance, we can see the impact of inventories on the pricing decision: prices and selling quantity for the existing product remain the same in the absence of inventories but change when inventories exist (Tables 3 and 4). The retailer's wholesale price advantages in retaining strategic inventories in Period 2 are well-documented literature (Anand et al. 2008; Arya and Mittendorf 2013; Mantin and Jiang 2017). The results also reflect that observation. If strategic inventories are held in the second period, it reduces the scale of the procurement volume and wholesale prices. The nature of wholesale and retail prices regarding the existing product quality remains the same if both products are offered. However, if only an upgraded product is offered in the second period, the pricing nature changes with the existing product quality level. Owing to the presence of an earlier version only as strategic inventories, the retailer might reduce the retail price of upgraded products compared with the scenario in which both versions are continued. Intuitively, the presence of an earlier version negatively affects the wholesale price (see Equation (C.27)). If the wholesale price decreases, the retail price also decreases. Indeed, the reason for removing (or continuing) an existing product is to replace it with a new-generation product (or provide more options to consumers). Although several other factors can affect decisions in pragmatic scenarios, this study demonstrates that retailers' strategic decisions have an impact. This may help as well as harm the manufacturer in terms of profit. We present the following lemma, highlighting the condition under which the retailer can able to carry inventories.

Lemma 4
- *While the manufacturer offers only the existing product or the existing product along with an upgraded or a downgraded product in the second period, the retailer carries strategic inventories if* $h \leq h_1 = \frac{\theta(1-\eta\theta)}{4}$. *Otherwise, the retailer does not carry strategic inventories.*
- *While the manufacturer offers only an upgraded product, the retailer carries strategic inventories of the existing product if* $h \leq h_2 = \frac{\theta(14-3\eta\theta(10-3\eta\theta))}{18(2-\eta\theta)}$. *Otherwise, the retailer does not carry strategic inventories.*

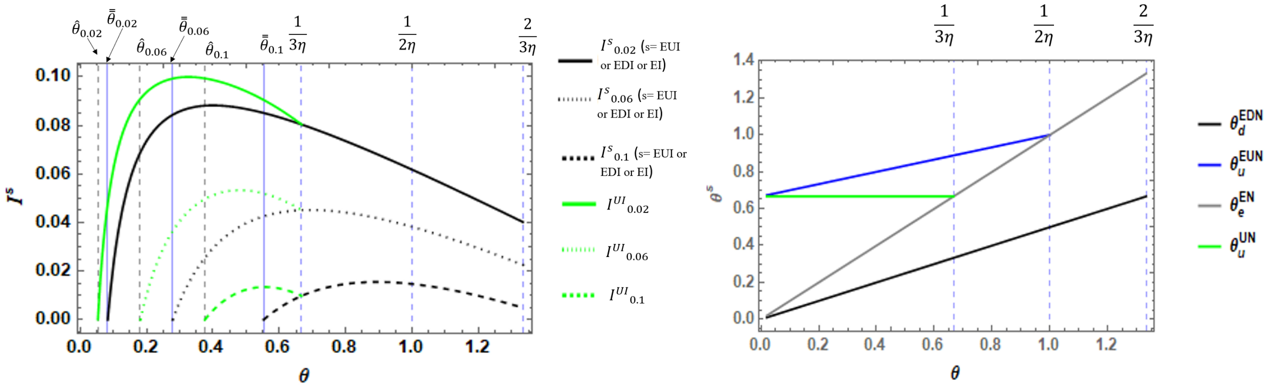
We refer to Appendix C and Table G.1 for a detailed explanation of various thresholds for holding cost (h) and product quality for the existing version (θ) used in this study. Thresholds h_1 and h_2 signify that if inventory-carrying costs are too high, strategic inventories become less beneficial to the retailer (see Figure G.1). It is intuitive to obtain such thresholds because the retailer may not retain inventories if the holding cost is too high. This result is consistent with that reported by Anand et al. (2008) and Desai et al. (2010). For instance, in our model setting, where the manufacturer continues only the existing product (Scenario EI), if the unit cost is negligible ($\eta \to 0$), and $\theta = 1$, then $h_1 = \frac{1}{4}$; a similar limit is noted by Anand et al. (2008) and Elahi et al. (2023). We verify that the profits of the manufacturer and retailer are both convex with respect to the holding cost (h) in Scenario EUI because $\frac{d^2\pi_m^{EUI}}{dh^2} = \frac{8}{17\theta} > 0$ and $\frac{d^2\pi_r^{EUI}}{dh^2} = \frac{152}{289\theta} > 0$, respectively. At $h = h_1$, the manufacturer's profit is minimal and remains the same as in Scenario EUN. Therefore, the manufacturer benefits if the retailer carries inventories for all $h < h_1$. However, this is not the case for the retailer. The retailer's profit is at its minimum at $h = \frac{59\theta(1-\eta\theta)}{304}$, and at that point ${\pi_r}_{min}^{EUI} = \frac{304+\eta\theta(2253-\eta\theta(4506-1645\eta\theta))}{32832\eta}$ and ${\pi_r}^{EUN} - {\pi_r}_{min}^{EUI} = -\frac{\theta(1-\eta\theta)^2}{1216} < 0$. The characteristics of the retailers' profits are consistent with those of Anand et al. (2008), Arya and Mittendorf (2013), and Mantin and Jiang (2017).

4.2.1 Volume of existing product inventories

The holding costs are typically proportional to the per-unit costs, and all the thresholds we identified (h_1, h_2) are also scaled to quality (θ). In addition, the quality–cost factor affects the upper thresholds of the holding cost. If the cost factor is too high, the product cost also increases, which affects the inventory volume. We also verified that inventory volume decreases with respect to η in all scenarios ($\frac{dI^{EUI}}{d\eta} = -\frac{5\theta}{34} < 0$ and $\frac{dI^{UI}}{d\eta} = -\frac{6((16-9\eta\theta(2-\eta\theta))(\theta+4h)+9h\eta\theta(4-3\eta\theta))}{(32-3\eta\theta(16-3\eta\theta))^2} < 0$). As η increases, the investment cost and wholesale prices also increase. Subsequently, the retailer might not carry too much inventories, and it reduces the upper thresholds of holding costs. As shown in Table 4, the inventory volume remains the same in Scenarios EUI, EDI, and EI. However, the volume changes in Scenario UI.

Lemma 5 *If $\theta \in (0, \frac{1}{3\eta})$, the retailer carries a high amount of inventories when only upgraded product is offered ($I^{UI} \geq I^{EUI}$) for $h \in \left(0, \frac{\theta(4-3\eta\theta(56-15\eta\theta))}{696-180\eta\theta}\right)$.*

If the holding cost is not too high and the manufacturer wants to discontinue the existing product, the retailer can carry some products, at least for price discrimination. We verify that I^{EUI} is always concave with respect to the quality of the existing product ($\frac{d^2 I^{EUI}}{d\theta^2} = -\frac{20h}{17\theta^3} < 0$); that is, increasing the quality of the existing product has an impact on the retailer's decision. If the quality of the existing product is high, the wholesale price is also high. However, the characteristic of the inventory volume with respect to the existing product quality in Scenario UI (I^{UI}) is problematic to establish analytically. We present a graphical illustration of the inventory level and product qualities in different scenarios in Figure 3.



(a) Inventory level

(b) Quality levels

Figure 3: (a) Inventory level in Scenarios EUI/EDI/EI and UI: $h = 0.02$, $h = 0.06$, $h = 0.1$, $\bar{\bar{\theta}} : I^{EI} = 0$ and $\hat{\theta} : I^{UI} = 0$; (b) Product qualities in four decentralized scenarios: $\eta = 0.5$, $\theta \in (0, \frac{2}{3\eta})$

Figure 3 demonstrates that the retailer may carry more inventories if the manufacturer only offers an upgraded product (Scenario UI in Figure 3a). However, the quality level of the upgraded product remains high if it is offered with the existing version (Scenario EUN in Figure 3b). Note that $\bar{\bar{\theta}}$ and $\hat{\theta}$ represent the thresholds where inventories become zero due to the quality impact. Therefore, we can see the interplay between new product introduction decisions and inventory volume in the following aspects: First, how much product will be retained as strategic inventories directly related to quality and holding cost? The retailer might not carry inventories if the quality is low and the holding cost is moderate (for instance: $\theta < 0.2$ and $h = 0.06$). However, high quality does not mean that the volume of strategic inventories is also high. Second, the retailer may intend to offer a product that the manufacturer discontinued. The retailer can withhold inventories if an upgraded or downgraded product is offered.

4.2.2 Transition of new product introduction

This subsection explores the impact of strategic inventories on the profitability of supply chain members. We compare profits in all scenarios where the retailer never carries inventories from the first to the second period, regardless of parameter values, and propose the following proposition where strategic inventories do not exist.

Proposition 1 *If the manufacturer introduces a new version in the second period and the retailer does not carry inventories, then the manufacturer's profit-maximizing strategy is*

$$S = \begin{cases} EUN & \text{if } 0 < \theta \leq \overline{\theta} \equiv \frac{2(32+9\cdot\sqrt[3]{2}-12\cdot\sqrt[3]{4})}{155\eta} \sim \frac{0.3134}{\eta} \\ EDN & \text{if } \overline{\theta} < \theta \leq \frac{2}{3\eta} \\ EN & \text{if } \frac{2}{3\eta} < \theta \leq \frac{1}{\eta} \end{cases}$$

We refer the reader to Appendix D.1 for detailed proof of Proposition 1. Additionally, we refer to Lemma F.3, representing the manufacturer's profit maximization equilibrium when only a downgraded product introduction is also a possibility. We focus our attention on the manufacturer as the retailer's profit, in this case, is simply half of the manufacturer's (see Table 3), so it follows the same strategy. We first note that the manufacturer's total selling quantity, that is, the sum of existing and new versions (either upgraded or downgraded) in the second period, remains high compared to the scenario where only a single product is offered (which can be seen from $q_{2e}^{EUN} + q_u^{EUN} - q_n^{UN} = \frac{1-3\eta\theta}{12} > 0$; $q_{2e}^{EUN} + q_u^{EUN} - q_{2e}^{EN} = 0$; $q_{2e}^{EDN} + q_d^{EDN} - q_u^{UN} = \frac{2-3\eta\theta}{4} > 0$; $q_{2e}^{EDN} + q_d^{EDN} - q_{2e}^{EN} = \frac{\eta\theta}{8} > 0$). Therefore, the manufacturer sells at least as high a volume of products by offering two versions as opposed to one only. Product quality and wholesale price for the upgraded version are both higher in Scenario EUN compared to Scenario UN (as can be inferred from $\delta^{EUN} - \delta^{UN} = \frac{1}{3} > 0$ and $w_u^{EUN} - w_u^{UN} = \frac{(5+\eta\theta)\theta}{18} > 0$). To gain intuition about the manufacturer's strategy choices, we note that the willingness to pay for a higher-quality product changes from one customer to another, and the existence of a lower-quality product can work as a reference. A customer may prefer a high-quality product if the joint price-quality trade-off is in favor of that product. The presence of both versions ensures that the manufacturer has substantial price-discrimination power. Therefore, when $0 < \theta \leq \overline{\theta}$, offering an upgraded version with an existing upgrade version is the optimal choice for the manufacturer when the quality of the earlier product is sufficiently low. If the quality of an existing product falls within a specific moderate range, the manufacturer should introduce another product such that the difference in quality between the two versions is sufficiently high so that the manufacturer can cover the cost of this product via price discrimination. Should this product be of a higher, or a lower, quality? Our analysis suggests that the quality difference is greater when this is a downgraded version (as can be induced from $\theta^{EUN} - \theta^{EN} = \frac{1-2\eta\theta}{3\eta} < \frac{\theta}{2} = \theta^{EN} - \theta^{EDN}$ when if $\theta \in (\overline{\theta}, \frac{2}{3\eta})$). Therefore, the rationale behind the introduction of the downgraded product is that it can ensure a higher quality discrimination coupled with wholesale price discrimination (observe that $w_u^{EUN} - w_{2e}^{EUN} = \frac{2(1+\eta\theta)(1-2\eta\theta)}{9\eta} < \frac{\theta(2+3\eta\theta)}{8} = w_{2e}^{EDN} - w_d^{EDN}$). Finally, when the quality of the existing version is sufficiently high ($\theta \geq \frac{2}{3\eta}$), the manufacturer should not introduce another high-quality upgraded version but might introduce another downgraded version. In that case, the presence of the downgraded version cannibalizes sales of the existing version (See q_{2e}^{EDN} in Table 3), which leads to a lower profit. Therefore, the manufacturer should continue the existing version only. We made the following proposition to demonstrate the manufacturer's optimal strategy when the retailer always carries inventories.

Proposition 2 *The retailer can carry strategic inventories if $h \leq max[h_1, h_2]$. Under those thresholds, the manufacturer's optimal strategy is as follows:*

1. *If* $0 < \theta \leq \ddot{\theta} \quad (0 \leq h_3 < h_1 < h_2)$
$$S = \begin{cases} UI & \text{if } 0 < h \leq h_3 \bigcup h_1 < h \leq h_2 \\ EUI & \text{if } h_3 < h \leq h_1 \end{cases}$$
2. *If* $\ddot{\theta} < \theta \leq \overline{\theta} \quad (0 < h_1 < h_2)$
$$S = \begin{cases} EUI & \text{if } 0 < h \leq h_1 \\ UI & \text{if } h_1 < h \leq h_2 \end{cases}$$
3. *If* $\overline{\theta} < \theta \leq \frac{1}{3\eta} \quad (0 < h_1 < h_2)$
$$S = \begin{cases} EDI & \text{if } 0 < h \leq h_1 \\ UI & \text{if } h_1 < h \leq h_2 \end{cases}$$
4. *If* $\frac{1}{3\eta} < \theta \leq \frac{2}{3\eta}$
$$S = EDI \ \text{if } 0 < h \leq h_1$$
5. *If* $\frac{2}{3\eta} < \theta \leq \frac{1}{\eta}$
$$S = EI \ \text{if } 0 < h \leq h_1$$

where, $h_3 = \frac{66-27\eta\theta(25-55\eta\theta+6\eta^2\theta^2)+\sqrt{51(1-3\eta\theta)(32-48\eta\theta+9\eta^2\theta^2)(12-\eta\theta(177-253\eta\theta+30\eta^2\theta^2)))}\theta}{36(1-3\eta\theta)(47-6\eta\theta)}$

We refer to Appendix D.2 for the proof of Proposition 2. By comparing Propositions 1 and 2, we observe the difference between the scenarios where the retailer does and does not carry inventories. First, the manufacturer shall offer only an upgraded version in the second period when the retailer holds inventories and the quality range of the existing product is low ($0 < \theta \leq \overline{\theta}$). However, the manufacturer should offer the existing along with an upgraded version within that quality range if the retailer does not hold strategic inventories. Second, for a moderate quality range of the existing product ($\overline{\theta} < \theta \leq \frac{1}{3\eta}$), the manufacturer shall also offer only upgraded products in the second period if the retailer carries strategic inventories. Meanwhile, the manufacturer shall always sell the existing along a downgraded version within that quality range to maximize profit if the retailer does not hold strategic inventories.

As shown in Figure 3a, if the manufacturer discontinues the existing version, the volume of strategic inventories remains considerably high ($I^{UI} > I^{EUI}$) compared to the scenario where both versions are offered. If the holding cost is sufficiently low, the retailer can hold a higher volume of inventories to improve the wholesale price negotiation power. Note that for a low quality existing version ($\theta \leq \ddot{\theta} \leq \overline{\theta}$), the manufacturer shall introduce an upgraded product at the expense of a small increment in the production cost. In that circumstance, the presence of the existing version, only because of the retailer's inventory, can ensure price and quality discrimination power for the manufacturer. Consequently, if the holding cost and existing product quality are sufficiently low, the manufacturer favors Scenario UI. According to Lemma 4, if the holding cost is high ($h > h_1$), the retailer does not hold strategic inventories if the manufacturer continues the existing version in the second period. However, suppose the manufacturer offers only the upgraded version, then the retailer holds inventories even if the holding cost is high ($h_1 < h < h_2$). We also observe that the wholesale price in the first period is comparatively lower than the scenarios when the manufacturer offers both existing and new versions in the second period ($w_{1e}^{EUI} - w_{1e}^{UI} = w_{1e}^{EDI} - w_{1e}^{UI} = \frac{(1-3\eta\theta)(36h(12+\eta\theta)+\theta(40-3\eta\theta(50+3\eta\theta)))}{102(32-3\eta\theta(16-3\eta\theta)))} > 0$ if $0 < \theta \leq \frac{1}{3\eta}$). Therefore, the manufacturer has a higher flexibility to introduce only an upgraded product with a higher holding cost range. Similar to Proposition 1, if the existing version quality is moderate ($\theta > \overline{\theta}$), the manufacturer may continue the existing product and introduce a downgraded product instead of an upgraded product because of a higher quality and wholesale price discrimination effect as explained earlier ($w_u^{EUI} - w_{2e}^{EUI} = \frac{2(1+\eta\theta)(1-2\eta\theta)}{9\eta} < \frac{\theta(24+61\eta\theta)+40h}{136} = w_{2e}^{EDI} - w_d^{EDI}$). Finally, combining Propositions 1 and 2 allows us to show the interplay between the strategic inventories and product offering decisions.

Proposition 3 *For any holding cost and optimal wholesale prices, when a manufacturer considers introducing a new version and the retailer may or may not carry inventories, the manufacturer's optimal strategy is as follows:*

1. *If* $0 < \theta \leq \ddot{\theta}$

$$S = \begin{cases} UI & \text{if } 0 < h \leq h_3 \\ EUI & \text{if } h_3 < h \leq h_1 \\ EUN & \text{if } h_1 < h \end{cases}$$

2. *If* $\ddot{\theta} < \theta \leq \overline{\theta}$

$$S = \begin{cases} EUI & \text{if } 0 < h \leq h_1 \\ EUN & \text{if } h_1 < h \end{cases}$$

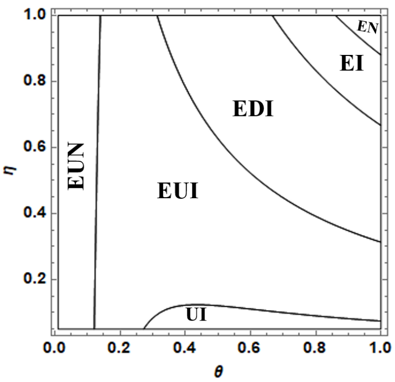
3. *If* $\overline{\theta} < \theta \leq \frac{2}{3\eta}$

$$S = \begin{cases} EDI & \text{if } 0 < h \leq h_1 \\ EDN & \text{if } h_1 < h \end{cases}$$

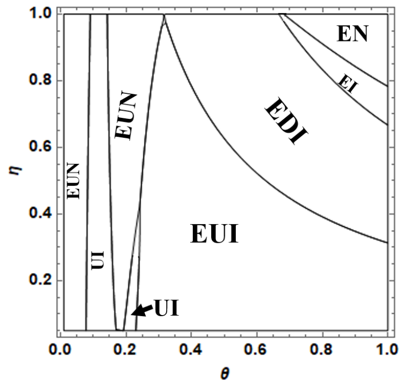
4. *If* $\frac{2}{3\eta} < \theta \leq \frac{1}{\eta}$

$$S = \begin{cases} EI & \text{if } 0 < h \leq h_1 \\ EN & \text{if } h_1 < h \end{cases}$$

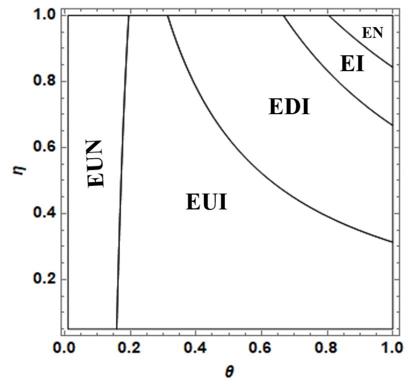
Appendix D.3 provides the proof of Proposition 3. We also refer to Lemma F.5, where the manufacturer can introduce a downgraded product. From the derivation of the optimal decisions, we summarize the feasible regions for each possible scenario based on the thresholds, as presented in Table G.1 in Appendix G. Figure 4 shows a graphical representation of the manufacturer's profit, retailer's profit, and total supply chain profit.



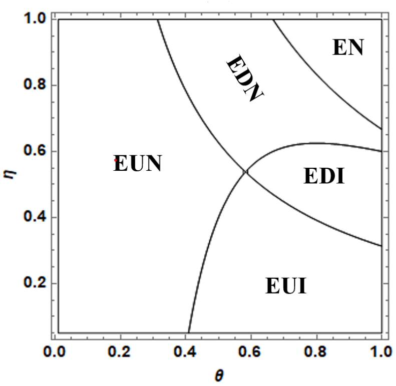
(a) Manufacturer's profit in decentralized scenarios (h=0.02)



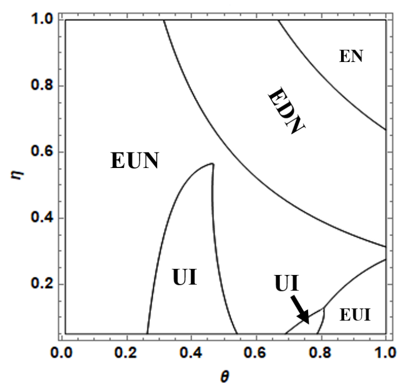
(b) Retailer's profit in decentralized scenarios (h=0.02)



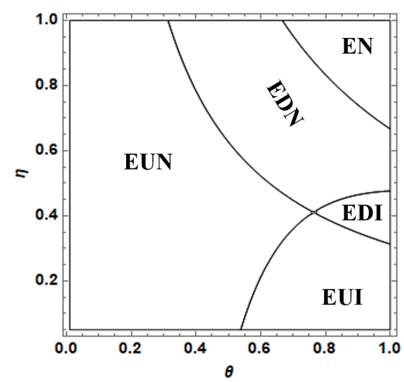
(c) Total supply chain profit in decentralized scenarios (h=0.02)



(d) Manufacturer's profit in decentralized scenarios (h=0.1)



(e) Retailer's profit in decentralized scenarios (h=0.1)



(f) Total supply chain profit in decentralized scenarios (h=0.1)

Figure 4: Region showing profit maximizing scenarios: $\theta \in (0, 1)$, $\eta \in (0.05, 1)$

In Proposition 1, we can confirm that the nature of the manufacturer's and retailer's profits in the absence of strategic inventories remains the same. However, this situation differs in the presence of strategic inventories. As pointed out by Anand et al. (2008); Arya and Mittendorf (2013), and Li et al. (2022b), a higher volume of inventories forces the manufacturer to price only for the retailer's residual demand ($Q_{2e} = q_{2e} - I$) in the second period. We found that downward pressure also propagates to wholesale price decisions and new generation prices (Equation (C.6)). This is precisely why the retailer is incentivized to accumulate inventories in the first period. Therefore, strategic inventories can play a significant role in the introduction of new products. The critical insight from Figure 4 is that if the manufacturer introduces an upgraded or downgraded product, the retailer might retain inventories of the existing version. Compared with scenarios in which the retailer never carries an earlier version, if the retailer does hold, the benefit of having the existing product is that the presence of both products can provide price differentiation power, which, in turn, ensures higher profits for both members. Thus, the cost factor was crucial. If the manufacturer is efficient in terms of cost (low η), it may discontinue the existing version. This also indicates that the preferences of the retailer and manufacturer may not be aligned. Therefore, the retailer may be better off if the holding cost is not sufficiently high (recall the thresholds h_1 and h_2 as defined earlier). The retailer's inventory holding aggravates the double marginalization effect in the first period and alleviates it in the second period. In this regard, if the manufacturer introduces an upgraded or downgraded version, the holding cost and the manufacturer's cost efficiency come into play. Therefore, the preferences differ. Recall the outcomes presented in Tables 3 and 4, the wholesale price for the existing product remains the same in Scenarios EUI, EI, and EDI. However, the quantities differ due to the presence of upgraded or downgraded versions. Consequently, the profits differ. The results presented in Table 4 also support the intuition that the impacts of holding cost and cost efficiency differ for retail and wholesale pricing. Overall, this study reveals that holding strategic inventories at equilibrium is optimal.

5 Discussion

Manufacturers typically offer similar types of products in order to satisfy customer preferences. For example, a smartphone manufacturer offers low, regular, and high-range products based on RAMs, displays, processors, camera specifications, price, and other features. Many criteria (e.g., geographical area) affect the categorization. The definition of a low-range product in the European and North American standards may easily pass for regular or even a high-range product in low-income countries. Similarly, for breakfast cereal manufacturers, simple cornflakes may be of the primary or regular type. However, the range consists of several versions based on flavor, fat or calorie content, retail price, and so forth. Introducing a new version is a critical strategic activity for firms to continue in the market. Researchers have studied strategic moves from different perspectives, such as supplier involvement (Song et al. 2011), customer integration (Flynn et al. 2010), product complexity, aspiring regulatory bodies, shrinking product release cycles (Schoenherr and Swink 2015), market potential, competitor aggressiveness, and complex value chains (Kotler et al. 2019). Furthermore, product price, technological sophistication, and innovation are common characteristics that affect a product's success (VanKleef et al.

2005; Xiao and Xu 2014). Numerous characteristics influence the success of a new version of a product, such as marketing and technological synergy, dedicated human and R&D resources, timing of introduction, fit with the organizational culture, and brand power (Kuester et al. 2012; Edgett 2011). However, research addressing the effects of earlier product inventories on bringing new versions to the market is relatively sparse. While researchers have mainly focused on the conceptualization and development processes of new versions and how they affect their success Evanschitzky et al. (2012), less attention has been paid to exploring the strategic effects of downstream members (Lee et al. 2011). Summarizing the analysis, we obtained the following key insights:

1. For any holding cost $h \in (0, \min\{h_1, h_2\})$, if the manufacturer introduces an upgraded or downgraded version, strategic inventories always benefit the manufacturer.
2. For any holding cost $h \in (0, h_3)$ and existing product quality $\theta \in (0, \ddot{\theta})$, the manufacturer can discontinue the existing version and introduce an upgraded version if the retailer holds strategic inventories.
3. For any holding cost $h \in (0, h_1)$ and existing product quality $\theta \in (\frac{2}{3\eta}, \frac{1}{\eta})$, the manufacturer can continue the existing version if the retailer holds strategic inventories.

To the best of our knowledge, previous studies have yet to comprehensively investigated the effects of strategic inventories on product introduction. Studies have identified several reasons for the failure of new products, such as inadequate information sharing, coordination among internal departments, external alignment and execution, product capability, pricing, environmental indicators, and competition. Manufacturers often struggle with product transitions, even when a new product meets all the requirements for success (Chen et al. 2016). The results demonstrate that the downstream retailer can significantly influence the strategic decision to substitute earlier products or continue with both products. The findings of this study provide managers with an overall understanding of risks and challenges and suggest possible courses of action. Finally, we present the product availability and quality specifications in Figure 5.

6 Conclusion

Today, businesses face rapidly changing environments in which technology, customer needs, competitors, and environmental regulations are constantly shifting. This study analytically examines the consequences of strategic inventories held by downstream retailers on their decisions to introduce upgraded or downgraded versions of a product. Two critical questions regarding

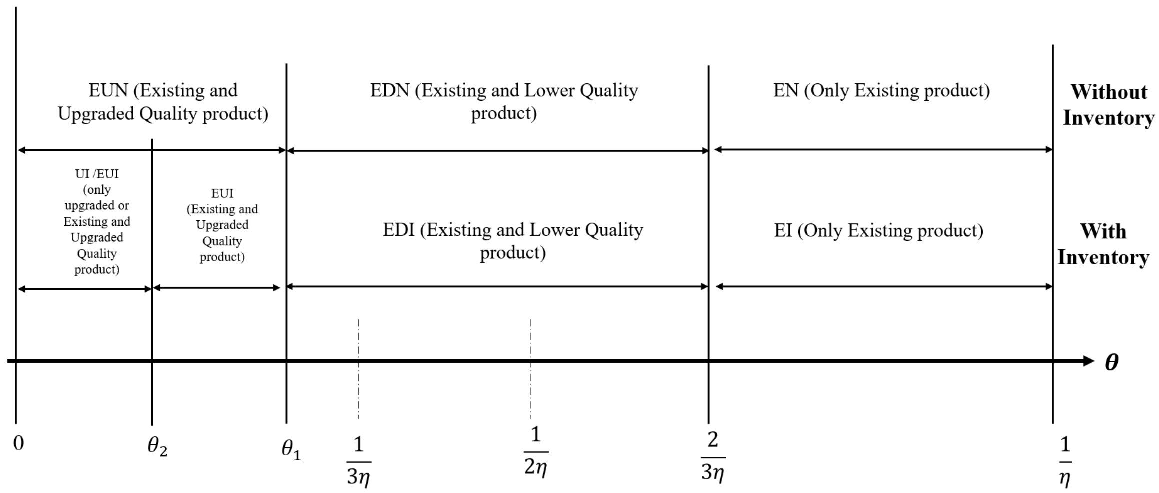


Figure 5: Product availability for customers in different scenarios

the introduction of a new product are whether a manufacturer should continue the existing product while introducing a new product and how a retailer influences the product introduction decision. Despite the increasing attention being paid to exploring the factors that influence the success of upgraded or downgraded products, the influence of existing product inventories when a manufacturer introduces an upgraded product is yet to be explored. Therefore, we formulate a stylized two-period supply chain model to study the interplay between product quality, existing product inventories, pricing, and vertical channel interactions.

This study contributes to existing literature in several ways. From a theoretical perspective, we provide insights into an area that has not received much attention in supply chain management research and is a challenging issue for any manufacturer: the influence of earlier product inventories on the success of product introductions. We demonstrate that strategic inventories can significantly affect the introduction of new product versions. The results suggest that a manufacturer can set the existing product wholesale price so that the retailer can maintain inventories, but discontinue the product in the second period. Therefore, inventory is critical when introducing new products. We find that a manufacturer can encourage a retailer to retain inventory while introducing an upgraded or new version. Therefore, strategic inventories can support the introduction of upgraded products. Carried-over units can cannibalize sales if an upgraded product is introduced in the second period. In this scenario, a careful pricing quality decision from the manufacturer's perspective, a trade-off between the amount of product to be carried over, and a purchase decision in the second period from the retailer's perspective can benefit all members. These trade-offs become relevant because it might cost the retailer less to carry over existing products instead of procuring all units of the existing product along with upgraded units, whereas the manufacturer sets wholesale prices dynamically. Our analysis shows that holding costs and existing product-quality thresholds are essential for determining the optimal course of action. These thresholds also reveal the maximum number of units a retailer can carry forward and the upgraded product quality level when offering one or both products. These findings can guide manufacturers in developing strategies for improving the success of upgraded product introductions.

Several directions for future research should be pursued. For example, we assume that existing products do not deteriorate, as in Mantin and Jiang (2017). Therefore, the results can be examined if the quality of existing products deteriorates. Next, the manufacturer uses additional promotional mechanisms (e.g., advertising and sales efforts while introducing upgraded products). Thus, it would be interesting to examine the influence of such a mechanism and the effect of strategic inventories on expenditures for manufacturer promotion and new product introduction. Finally, a simple extension of this study is to analyze a scenario in which a manufacturer can introduce both upgraded and downgraded products.

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Declaration of Competing Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendices

A Derivation of centralized decisions

Before presenting the main model, we derive the outcome of a centralized supply chain as a benchmark and explore the newer version's introduction decision and the corresponding retail prices and qualities when the manufacturer sells its products *directly* to consumers. In a centralized decision setting, strategic inventories do not exist ($I = 0$), and the wholesale pricing decision has no impact. For instance, in a centralized supply chain, if the manufacturer offers both upgraded and existing products (Scenario CEU) in the second period, then the profit function in a centralized supply chain is obtained as follows (Equations (6)-(9)):

$$\Pi_2(q_{2e}, q_u, \delta) = (p_{2e} - \eta\theta^2)q_{2e} + (p_u - \eta\delta^2\theta^2)q_u \tag{A.1}$$

Equation (A.1) is a function of three variables (q_{2e}, q_u, δ), and after solving the first-order conditions $\left(\frac{\partial \Pi_2}{\partial q_{2e}} = 0; \frac{\partial \Pi_2}{\partial q_u} = 0; \frac{\partial \Pi_2}{\partial \delta} = 0\right)$, the following four sets of solutions are obtained:

$$\begin{aligned}
\{q_{2e1}, q_{u1}, \delta_1\} &\equiv \left\{\frac{1-\eta\theta}{2}, 0, 1\right\} \\
\{q_{2e2}, q_{u2}, \delta_2\} &\equiv \left\{\frac{3\eta\theta-1}{2}, 1-2\eta\theta, 1\right\} \\
\{q_{2e3}, q_{u3}, \delta_3\} &\equiv \left\{\frac{1-\eta\theta}{2}, 0, \frac{1}{\eta\theta}-1\right\} \\
\{q_{2e4}, q_{u4}, \delta_4\} &\equiv \left\{\frac{1+\eta\theta}{6}, \frac{1-2\eta\theta}{3}, \frac{1}{3}\left(1+\frac{1}{\eta\theta}\right)\right\}
\end{aligned}$$

The Hessian matrix (H^{CEU}) for the profit function in Equation (A.1) is obtained as follows:

$$H^{CEU} = \begin{bmatrix} \frac{\partial^2 \Pi_2}{\partial {q_{2e}}^2} & \frac{\partial^2 \Pi_2}{\partial q_{2e} \partial q_u} & \frac{\partial^2 \Pi_2}{\partial q_{2e} \partial \delta} \\ \frac{\partial^2 \Pi_2}{\partial q_{2e} \partial q_u} & \frac{\partial^2 \Pi_2}{\partial {q_u}^2} & \frac{\partial^2 \Pi_2}{\partial q_u \partial \delta} \\ \frac{\partial^2 \Pi_2}{\partial q_{2e} \partial \delta} & \frac{\partial^2 \Pi_2}{\partial q_u \partial \delta} & \frac{\partial^2 \Pi_2}{\partial \delta^2} \end{bmatrix} = \begin{bmatrix} -2\theta & -2\theta & 0 \\ -2\theta & -2\delta\theta & \theta(1-2q_u-2\delta\eta\theta) \\ 0 & \theta(1-2q_u-2\delta\eta\theta) & -2q_u\eta\theta^2 \end{bmatrix}$$

Note that the values of principle minors at the second solution are: $|H_1^{CEU}|_{\{q_{2e4}, q_{u4}, \delta_4\}} = -2\theta < 0$; $|H_2^{CEU}|_{\{q_{2e4}, q_{u4}, \delta_4\}} = \frac{4\theta(1-2\eta\theta)}{3\eta} > 0$; and $|H_3^{CEU}|_{\{q_{2e4}, q_{u4}, \delta_4\}} = -\frac{2\theta^3(1-2\eta\theta)^2}{3} < 0$, respectively if $\theta < \frac{1}{2\eta}$. Therefore, the profit function is concave if $\theta < \frac{1}{2\eta}$. We verified that the first three solutions fail to satisfy the concavity condition. Using the second period's response, the first-period profit function can be obtained as:

$$\Pi(q_{1e}) = \theta q_{1e}(1 - q_{1e} - \eta\theta) + \frac{(4-5\eta\theta)(1+\eta\theta)^2}{108\eta} \tag{A.2}$$

The profit function in Equation (A.2) is concave in q_{1e} ($\frac{\partial^2 \Pi}{\partial q_{1e}^2} = -2\theta < 0$). Therefore, solving the first order condition ($\frac{\partial \Pi}{\partial q_{1e}} = 0$), the optimal response is obtained as follows:

$$q_{1e} = \frac{1-\eta\theta}{2} \tag{A.3}$$

Using back substitution, we obtain a response in Scenario CEU as presented in Table A.1. Following a similar procedure, we also get the reactions in other scenarios (Scenarios CED, CU, CE).

Table A.1: Optimal decisions for a centralized supply chain

Variables	Scenario CEU	Scenario CU	Scenario CE	Scenario CED
q^s_{1e}	$\frac{1-\eta\theta}{2}$	$\frac{1-\eta\theta}{2}$	$\frac{1-\eta\theta}{2}$	$\frac{1-\eta\theta}{2}$
p^s_{1e}	$\frac{(1+\eta\theta)\theta}{2}$	$\frac{(1+\eta\theta)\theta}{2}$	$\frac{(1+\eta\theta)\theta}{2}$	$\frac{(1+\eta\theta)\theta}{2}$
q^s_{2e}	$\frac{1+\eta\theta}{6}$	-	$\frac{1-\eta\theta}{2}$	$\frac{2-3\eta\theta}{4}$
p^s_{2e}	$\frac{(1+\eta\theta)\theta}{2}$	-	$\frac{(1+\eta\theta)\theta}{2}$	$\frac{(1+\eta\theta)\theta}{2}$
q^s_k	$\frac{1-2\eta\theta}{3}$	$\frac{1}{3}$	-	$\frac{\eta\theta}{2}$
p^s_k	$\frac{(1+\eta\theta)(4+\eta\theta)}{18\eta}$	$\frac{2}{9\eta}$	-	$\frac{(2+\eta\theta)\theta}{8}$
δ^s_k	$\frac{1+\eta\theta}{3\eta\theta}$	$\frac{1}{3\eta\theta}$	-	$\frac{1}{2}$
Π^s	$\frac{(2-\eta\theta)(1+\eta\theta(8-11\eta\theta))}{54\eta}$	$\frac{4+27\eta\theta(1-\eta\theta)^2}{108\eta}$	$\frac{(1-\eta\theta)^2\theta}{2}$	$\frac{\theta(8(1-\eta\theta)^2+\eta^2\theta^2)}{16}$

Note: In Scenario CEU, both existing and upgraded products are offered; in Scenario CU, only upgraded product is offered; in Scenario CE, only existing product is offered; and in Scenario CED, both existing and downgraded products are offered.

We made the following lemma characterizing the profit maximization choice of a centralized firm.

Lemma A.1 *In the centralized setting, the profit maximization solution is such that*

$$S = \begin{cases} CEU & \text{if } 0 < \theta \leq \overline{\theta} \equiv \frac{2(32+9\cdot\sqrt[3]{2}-12\cdot\sqrt[3]{4})}{155\eta} \sim \frac{0.3134}{\eta} \\ CED & \text{if } \overline{\theta} < \theta \leq \frac{2}{3\eta} \\ CE & \text{if } \frac{2}{3\eta} < \theta \leq \frac{1}{\eta} \end{cases}$$

Proof: Comparing profits in centralized scenarios as presented in Table A.1, we obtain the following relations: $\Pi^{CEU} - \Pi^{CE} = \frac{(1-2\eta\theta)^3}{27\eta} > 0$; $\Pi^{CEU} - \Pi^{CU} = \frac{\theta(3(1-3\eta\theta)(1+\eta\theta)+4\eta^2\theta^2)}{108} > 0$; $\Pi^{CU} - \Pi^{CE} = \frac{(1-3\eta\theta)^2(4-3\eta\theta)}{108\eta} > 0$; $\Pi^{CED} - \Pi^{CE} = \frac{\eta^2\theta^3}{16} > 0$; $\Pi^{CEU} - \Pi^{CED} = \frac{16-\eta\theta(96-\eta\theta(192-155\eta\theta))}{432\eta} > 0$ if $\theta \leq \frac{2(32+9\times 2^{\frac{1}{3}}-12\times 2^{\frac{2}{3}})}{155\eta} = \overline{\theta}$.

B Complete derivation of optimal responses in decentralized scenarios without inventory

In the following subsections, we derive optimal responses for the members when the manufacturer offers (i) existing and upgraded products (Scenario EUN), (ii) only existing products (Scenario EN), (iii) only upgraded products (Scenario UN) in the second period. Note that the derivation of optimal decision when a manufacturer offers the existing product with a downgraded product (Scenario EDN) is similar to Scenario EUN, and hence, we omitted the proof.

B.1 Manufacturer offers both upgraded and existing products:

If both products are available in the second period, then the inverse demand function can be obtained from Equations (1) and (2), as:

$$p_{1e} = (1 - q_{1e})\theta, \quad p_{2e} = (1 - q_{2e} - q_u)\theta, \quad p_u = ((1 - q_u)\delta - q_{2e})\theta \tag{B.1}$$

Substituting $I = 0$ in Equation (9), we obtain the profit function in the second period for the retailer as:

$$\pi_{r2}(q_{2e}, q_u) = q_{2e}(p_{2e} - w_{2e}) + q_u(p_u - w_u) \tag{B.2}$$

Because $\frac{\partial^2 \pi_{r2}}{\partial {q_{2e}}^2} = -2\theta < 0$ and $\frac{\partial^2 \pi_{r2}}{\partial {q_{2e}}^2} \cdot \frac{\partial^2 \pi_{r2}}{\partial {q_u}^2} - \left(\frac{\partial^2 \pi_{r2}}{\partial q_{2e} \partial q_u}\right)^2 = 4(\delta - 1)\theta^2 > 0$, the retailer's profit function is concave in q_{2e} and q_u. Solving first order conditions for the retailer's profit function, $\left(\frac{\partial \pi_{r2}}{\partial q_{2e}} = 0 \text{ and } \frac{\partial \pi_{r2}}{\partial q_u} = 0\right)$, simultaneously, the selling quantity for the second period, obtained as follows:

$$q_{2e}(w_{2e}, w_u, \delta) = \frac{w_u - \delta w_{2e}}{2(\delta - 1)\theta}, \quad q_u(w_{2e}, w_u, \delta) = \frac{(\delta - 1)\theta - w_u + w_{2e}}{2(\delta - 1)\theta} \tag{B.3}$$

Note that the purchase quantity for each product is a decreasing function of their respective wholesale prices (w_{2e} and w_u). Therefore, if the manufacturer sets higher wholesale prices, then the retailer might not procure products in the second period, and those wholesale price thresholds can be obtained by solving $q_{2e} = 0$ and $q_u = 0$. On simplification, the upper bounds for wholesale prices are obtained as follows:

$$\ddot{w}_{2e}(w_u, \delta) = \frac{w_u}{\delta} \tag{B.4}$$

$$\ddot{w}_u(w_{2e}, \delta) = w_{2e} + (\delta - 1)\theta \tag{B.5}$$

Therefore, the selling quantities for the retailer based on the wholesale prices offered by the manufacturer are as follows:

Lemma B.1 *The selling quantity of the retailer in the second period will be*

$$q_{2e}(w_{2e}, w_u, \delta) = \begin{cases} \frac{w_u - \delta w_{2e}}{2(\delta-1)\theta} & \text{if } w_{2e} < \ddot{w}_{2e} \\ 0, & \text{otherwise} \end{cases}$$

$$q_u(w_{2e}, w_u, \delta) = \begin{cases} \frac{(\delta-1)\theta - w_u + w_{2e}}{2(\delta-1)\theta} & \text{if } w_u < \ddot{w}_u \\ 0, & \text{otherwise} \end{cases}$$

Therefore, we need to explore responses for the retailer related to the following possibilities:

- The manufacturer offers wholesale prices of both products below those thresholds,
- The manufacturer offers the wholesale price of the existing product above the threshold ($\ddot{w}_{2e}$),
- The manufacturer offers the wholesale price of the upgraded product above the threshold ($\ddot{w}_u$),
- The manufacturer offers the wholesale prices of both products above the thresholds.

Using the optimal responses of the retailer obtained in Equation (B.3), the second-period profit function for the manufacturer is obtained as:

$$\pi_{m2}(w_{2e}, w_u, \delta) = \frac{((\delta-1)\theta + w_{2e} - w_u)(w_u - \eta\delta^2\theta^2) - (w_{2e}\delta - w_u)(w_{2e} - \eta\theta^2)}{2\theta(\delta-1)} \tag{B.6}$$

First, we derive the Hessian matrix as presented below to examine the nature of the profit function in Equation (B.6) as follows:

$$H_1 = \begin{bmatrix} \frac{\partial^2\pi_{m2}}{\partial {w_{2e}}^2} & \frac{\partial^2\pi_{m2}}{\partial w_{2e}\partial w_u} & \frac{\partial^2\pi_{m2}}{\partial w_{2e}\partial\delta} \\ \frac{\partial^2\pi_{m2}}{\partial w_{2e}\partial w_u} & \frac{\partial^2\pi_{m2}}{\partial {w_u}^2} & \frac{\partial^2\pi_{m2}}{\partial w_u\partial\delta} \\ \frac{\partial^2\pi_{m2}}{\partial w_{2e}\partial\delta} & \frac{\partial^2\pi_{m2}}{\partial w_u\partial\delta} & \frac{\partial^2\pi_{m2}}{\partial\delta^2} \end{bmatrix} = \begin{bmatrix} -\frac{\delta}{\theta(\delta-1)} & \frac{1}{\theta(\delta-1)} & \frac{w_{2e}-w_u}{\theta(\delta-1)^2} - \frac{\eta\theta}{2} \\ \frac{1}{\theta(\delta-1)} & -\frac{1}{\theta(\delta-1)} & -(\frac{w_{2e}-w_u}{\theta(\delta-1)^2} - \frac{\eta\theta}{2}) \\ \frac{w_{2e}-w_u}{\theta(\delta-1)^2} - \frac{\eta\theta}{2} & -(\frac{w_{2e}-w_u}{\theta(\delta-1)^2} - \frac{\eta\theta}{2}) & -\frac{(w_{2e}-w_u)^2}{\theta(\delta-1)^3} - \eta\theta^2 \end{bmatrix}$$

Note that the principle minors are $|H_1|_{1\times1} = -\frac{\delta}{\theta(\delta-1)} < 0$; $|H_1|_{2\times2} = \frac{1}{\theta^2(\delta-1)} > 0$; and $|H_1|_{3\times3} = \frac{\eta(4(w_u-w_{2e})-(\delta-1)\theta(4-(\delta-1)\eta\theta))}{\theta(\delta-1)^2}$, i.e., profit function is concave if $|H_1|_{3\times3} < 0$. Now, solving the first order conditions with respect to w_{2e}, w_u and δ, we obtain the following two sets of solution:

$$\begin{aligned} \{w_{2e}(\theta), w_u(\theta), \delta(\theta)\} &\equiv \left\{\frac{\theta(1+\eta\theta)}{2}, \frac{2-\eta\theta(3-\eta\theta)}{2\eta}, \frac{1-\eta\theta}{\eta\theta}\right\} \\ \{w_{2e}(\theta), w_u(\theta), \delta(\theta)\} &\equiv \left\{\frac{\theta(1+\eta\theta)}{2}, \frac{(4+\eta\theta)(1+\eta\theta)}{18\eta}, \frac{1+\eta\theta}{3\eta\theta}\right\} \end{aligned} \tag{B.7}$$

One can verify that the second set of solutions given in Equation (B.7) satisfy the concavity condition $|H_1|_{3\times3}< 0$ $\left(|H_1|_{3\times3\left\{\frac{\theta(1+\eta\theta)}{2},\frac{(4+\eta\theta)(1+\eta\theta)}{18\eta},\frac{1+\eta\theta}{3\eta\theta}\right\}} = -\frac{3\eta^2\theta}{4} < 0\right)$, but the first set of solutions do not satisfy the concavity condition $|H_1|_{3\times3}< 0$ $\left(|H_1|_{3\times3\left\{\frac{\theta(1+\eta\theta)}{2},\frac{2-\eta\theta(3-\eta\theta)}{2\eta},\frac{1-\eta\theta}{\eta\theta}\right\}} = \frac{\eta^2\theta}{4} > 0\right)$. Substituting the manufacturer's response from Equation (B.7) in Equation (B.3), we obtain the demand for the products in Period 2 as follows:

$$q_{2e}(\theta) = \frac{1+\eta\theta}{12}, \quad q_u(\theta) = \frac{1-2\eta\theta}{6} \tag{B.8}$$

By comparing the optimal wholesale price of the existing product with the boundary value (Equations (B.4)), we obtain $\ddot{w}_{2e}(\theta) - w_{2e}(\theta) = \frac{\theta(1-2\eta\theta)}{6(1+\eta\theta)} > 0$ if $\theta < \frac{1}{2\eta}$, and that of the upgraded product with the threshold (Equation (B.5)), we get $\ddot{w}_u - w_u = \frac{(1-2\eta\theta)^2}{9\eta} > 0$. Therefore, the manufacturer introduces the upgraded product along with the existing product if $\theta < \frac{1}{2\eta}$. Using the responses obtained in Equations (B.7) and (B.3), the total profit function for the retailer in two periods is obtained as:

$$\pi_r(q_{1e}) = q_{1e}\theta(1-q_{1e}) - w_{1e}q_{1e} + \frac{4-5\eta\theta(1+\eta\theta)^2}{432\eta} \tag{B.9}$$

Because, $\frac{\partial^2\pi_r}{\partial {q_{1e}}^2} = -2\theta < 0$, the profit function for the retailer is concave in q_{1e}. Now solving the first-order condition for the profit function in Equation (B.9), the response for the retailer is obtained as follows:

$$q_{1e}(w_{1e}) = \frac{\theta - w_{1e}}{2\theta} \tag{B.10}$$

Finally, substituting Equations (B.10) and (B.7) in Equation (B.6), the total profit for the manufacturer in two periods is obtained as:

$$\pi_m(w_{1e}) = \frac{(w_{1e}+\theta)\left(w_{1e}-\eta\theta^2\right)}{2\theta} + \frac{4-5\eta\theta(1+\eta\theta)^2}{216\eta} \tag{B.11}$$

Because $\frac{d^2\pi_m}{dw_{1e}^2} = -\frac{1}{\theta} < 0$, therefore, the manufacturer's profit function is concave. Solving the first order condition, we obtain the wholesale price in the first period as

$$w_{1e} = \frac{\theta(1+\eta\theta)}{2} \tag{B.12}$$

Using back substitution, the optimal response in Scenario EUN is obtained and presented in Table 3. The derivation of the optimal decision for Scenarios EDN is similar, so we omitted the detail.

B.2 Manufacturer offers only existing products in the second period:

In this scenario, the profit function of the retailer in the second period is obtained as follows:

$$\pi_{r2}(q_{2e}) = q_{2e}(p_{2e} - w_{2e}) \tag{B.13}$$

One can verify that the profit function in Equation (B.13) is concave because $\frac{d^2\pi_{r2}}{d{q_{2e}}^2} = -2\theta < 0$. Solving first order condition, the demand is obtained as follows:

$$q_{2e}(w_{2e}) = \frac{\theta - w_{2e}}{2\theta}; \tag{B.14}$$

Total demand in the second period decreases with the wholesale price. Therefore, if the manufacturer sets the wholesale price for the existing product above $\hat{w}_{2e}(I) = \theta$, then the retailer will not buy the existing product in the second period. Using the response obtained in Equation (B.14), the profit function for the manufacturer becomes:

$$\pi_{m2}(w_{2e}) = \frac{(w_{2e} - \eta\theta^2)(\theta - w_{2e})}{2\theta} \tag{B.15}$$

Because $\frac{d^2\pi_{m2}}{d{w_{2e}}^2} = -\frac{1}{\theta} < 0$, the profit function for the manufacturer is concave. By solving the first-order condition, the wholesale price for the existing product in the second period is obtained as follows:

$$w_{2e}(\theta) = \frac{\theta(1 + \eta\theta)}{2} \tag{B.16}$$

Therefore, the demand ($q_{2e} = \frac{1-\eta\theta}{4}$), is positive if $\theta < \frac{1}{\eta}$. Note that if only existing product is continued in Period 2 and the retailer does not retain inventory, the profit functions for both periods remain the same. Consequently, decisions in both periods remain identical. Using back substitution, the optimal response in Scenario EN is obtained and presented in Table 3.

B.3 Manufacturer offers only upgraded product in the second period:

In this strategy, the manufacturer offers an existing version in the first period and an upgraded version in the second period. Therefore, the profit function of the retailer in the second period is obtained as follows:

$$\pi_{r2} = q_u(p_u - w_u) \tag{B.17}$$

The profit function in Equation (B.17) is concave because $\frac{d^2\pi_{r2}}{d{q_u}^2} = -2\delta\theta < 0$, and we obtain the selling quantity for the upgraded product by solving the first-order condition as follows:

$$q_u(w_u, \delta) = \frac{\delta\theta - w_u}{2\delta\theta} \tag{B.18}$$

Once again, the order quantity in Equation (B.18) decreases with the wholesale price. The retailer cannot buy any product in the second period if the manufacturer sets a wholesale price above the threshold $w_u = \hat{w}_u(\delta) = \delta\theta$. Using the response given in Equation (B.18), the profit function for the manufacturer becomes

$$\pi_{m2}(w_u, \delta) = \frac{(\delta\theta - w_u)\,(w_u - \eta\theta^2\delta^2)}{2\delta\theta} \tag{B.19}$$

Solving first-order conditions, we get the following two sets of solutions:

$$\begin{aligned} \{w_u(\theta), \delta(\theta)\} &\equiv \left\{\frac{2}{9\eta}, \frac{1}{3\eta}\right\} \\ \{w_u(\theta), \delta(\theta)\} &\equiv \left\{\frac{1}{\eta}, \frac{1}{\eta}\right\} \end{aligned} \tag{B.20}$$

One can verify that the profit function in Equation (B.19) is concave for the first set of solutions given in Equation (B.20), because $\frac{\partial^2 \pi_{m2}}{\partial {w_u}^2} = -2\theta < 0$, and $\frac{\partial^2 \pi_{m2}}{\partial {w_u}^2} \cdot \frac{\partial^2 \pi_{m2}}{\partial \delta^2} - \left(\frac{\partial^2 \pi_{m2}}{\partial w_u \partial \delta}\right)^2 = \frac{3\eta^2\theta^2}{4} > 0$. The demand of the upgraded product is $q_u = \frac{1}{6} > 0$. Substituting the response obtained in Equations (B.18) and (B.20) in Equation (B.17), the total profit for the retailer is obtained as:

$$\pi_r(q_{1e}) = q_{1e}(\theta - \theta q_{1e} - w_{1e}) + \frac{1}{108\eta} \tag{B.21}$$

The profit function for the retailer in Equation (B.21) is concave because $\frac{\partial^2 \pi_r}{\partial {q_{1e}}^2} = -2\theta < 0$. By solving the first-order condition, the response for the retailer is obtained as follows:

$$q_{1e}(w_{1e}) = \frac{\theta - w_{1e}}{2\theta} \tag{B.22}$$

Substituting responses obtained from Equations (B.22) and (B.20) in Equation (B.19), the total profit for the manufacturer in the first period is obtained as:

$$\pi_m(w_{1e}, \delta) = \frac{(w_{1e} - \eta\theta^2)(\theta - w_{1e})}{2\theta} + \frac{1}{54\eta} \tag{B.23}$$

Because $\frac{d^2\pi_m}{dw_{1e}^2} = -\frac{1}{\theta} < 0$, the profit function is concave, and solving the first order condition, the wholesale price is obtained as:

$$w_{1e} = \frac{\theta(1 + \eta\theta)}{2} \tag{B.24}$$

Using back substitution, the optimal response in Scenario UN is obtained and presented in Table 3.

C Complete derivation of optimal responses in decentralized scenarios in the presence of strategic inventories

Similar to the previous section, we derive optimal responses for the members when the retailer caries inventories and the manufacturer offers (i) existing and upgraded products (Scenario EUI), (ii) only existing products (Scenario EI), (iii) only upgraded products (Scenario UI) in the second period. The derivation for Scenario EDI is similar to Scenario EUI, so we omit the details.

C.1 Manufacturer offers both upgraded and existing products:

The second-period profit function for the retailer, given in Equation (9), is concave in q_{2e} and q_u because $\frac{\partial^2 \pi_{r2}}{\partial {q_{2e}}^2} = -2\theta < 0$ and $\frac{\partial^2 \pi_{r2}}{\partial {q_{2e}}^2} \cdot \frac{\partial^2 \pi_{r2}}{\partial {q_u}^2} - \left(\frac{\partial^2 \pi_{r2}}{\partial q_{2e} \partial q_u}\right)^2 = 4(\delta-1)\theta^2 > 0$,. Solving first order conditions for the retailer's profit function $\left(\frac{\partial \pi_{r2}}{\partial q_{2e}} = 0 \text{ and } \frac{\partial \pi_{r2}}{\partial q_u} = 0\right)$, simultaneously, the demand of the products are obtained as follows:

$$\left.\begin{aligned} q_{2e}(w_{2e}, w_u, \delta) &= \frac{w_u - \delta w_{2e}}{2(\delta-1)\theta} \\ q_u(w_{2e}, w_u, \delta) &= \frac{(\delta-1)\theta - w_u + w_{2e}}{2(\delta-1)\theta} \end{aligned}\right\} \tag{C.1}$$

From Equation (C.1), we obtain the purchase quantities in Period 2 as follows:

$$\left.\begin{aligned} Q_{2e}(w_{2e}, w_u, \delta) &= q_{2e} - I = \frac{w_u - \delta w_{2e} - 2(\delta-1)\theta I}{2(\delta-1)\theta} \\ Q_u(w_{2e}, w_u, \delta) &= \frac{(\delta-1)\theta - w_u + w_{2e}}{2(\delta-1)\theta} \end{aligned}\right\} \tag{C.2}$$

Note that the purchase quantity for each product is a decreasing function of their respective wholesale prices (w_{2e} and w_u). Therefore, if the manufacturer sets higher wholesale prices, then the retailer might not procure products in the second period, and those wholesale price thresholds can be obtained by solving $Q_{2e} = 0$ and $Q_u = 0$, respectively. On simplification, the upper bounds for wholesale prices are obtained as follows:

$$\overline{w}_{2e}(I, w_u, \delta) = \frac{w_u - 2\theta I(\delta-1)}{\delta} \tag{C.3}$$

$$\overline{w}_u(I, w_{2e}, \delta) = w_{2e} + (\delta-1)\theta \tag{C.4}$$

Therefore, the selling quantity for the retailer based on the wholesale prices offered by the manufacturer is presented in the following lemma:

Lemma C.1 *The selling quantities of the retailer in the second period are as follows:*

$$q_{2e}(w_{2e}, w_u, \delta) = \begin{cases} \frac{w_u - \delta w_{2e}}{2(\delta-1)\theta} & \text{if } w_{2e} < \overline{w}_{2e} \\ I, & \text{otherwise} \end{cases}$$

$$q_u(w_{2e}, w_u, \delta) = \begin{cases} \frac{(\delta-1)\theta - w_u + w_{2e}}{2(\delta-1)\theta} & \text{if } w_u < \overline{w}_u \\ 0, & \text{otherwise} \end{cases}$$

Consequently, we need to explore responses for the retailer related to the following possibilities:

- The manufacturer offers wholesale prices below the thresholds ($w_{2e} \leq \overline{w_{2e}}, w_u \leq \overline{w_u}$),
- The manufacturer offers the wholesale price of the existing product above the threshold ($w_{2e} \geq \overline{w_{2e}}$),
- The manufacturer offers the wholesale price of the upgraded product above the threshold ($w_u \geq \overline{w_u}$),
- The manufacturer offers the wholesale prices of both products above the thresholds ($w_{2e} \geq \overline{w_{2e}}, w_u \geq \overline{w_u}$).

Using the optimal responses of the retailer obtained in Equation (C.1), the second-period profit function for the manufacturer is obtained as:

$$\pi_{m2}(w_{2e}, w_u, \delta) = \frac{(\delta-1)\left(\theta\left(\eta\theta^2\left(2I-\delta^2\right)+\eta\theta(\delta+1)w_u+w_u\right)-w_{2e}\theta(2I+\eta\delta\theta)-w_{2e}^2\right)-(w_{2e}-w_u)^2}{2\theta(\delta-1)} \tag{C.5}$$

Now, solving the first order conditions with respect to w_{2e} and w_u, we get the manufacturer's second period response as:

$$\left.\begin{aligned} w_{2e}(I,\delta) =& \frac{\theta(1+\eta\theta-2I)}{2} \\ w_u(I,\delta) =& \frac{\theta(\delta+\delta^2\eta\theta-2I)}{2} \end{aligned}\right\} \tag{C.6}$$

Comparing Equation (C.6) with Equation (B.7), one can see the detrimental effect of strategic inventory on the wholesale prices for both the products. If the retailer holds an earlier version in Period 1 and offers those in Period 2, it affects the manufacturer's wholesale price as the market is segmented. The profit function in Equation (C.5) is concave, because $\frac{\partial^2\pi_{m2}}{\partial {w_{2e}}^2} = -\frac{\delta}{\theta(\delta-1)} < 0$ and $\frac{\partial^2\pi_{m2}}{\partial {w_{2e}}^2} \cdot \frac{\partial^2\pi_{m2}}{\partial {w_u}^2} - \left(\frac{\partial^2\pi_{m2}}{\partial w_{2e}\partial w_u}\right)^2 = \frac{1}{\theta^2(\delta-1)} > 0$, respectively. Substituting the manufacturer's response from Equation (C.6) in Equation (C.1), we obtain the demand for the products in Period 2 as follows:

$$\left.\begin{aligned} q_{2e}(I,\delta) =& \frac{\eta\delta\theta+2I}{4} \\ q_u(I,\delta) =& \frac{1-(\delta+1)\eta\theta}{4} \end{aligned}\right\} \tag{C.7}$$

By comparing the optimal wholesale price of the existing product with the boundary value (Equations (C.3)), we obtain $\overline{w}_{2e}(I,\delta) - w_{2e}(I,\delta) = \frac{\theta(\delta-1)(\eta\delta\theta-2I)}{2t} > 0$ if $I < \overline{I}(\delta) = \frac{\eta\delta\theta}{2}$. Therefore, if the manufacturer offers both products in the second period, then the retailer might retain a maximum $I = \overline{I}$ amount of inventories. From the upper bound, it is clear that the retailer might not hold too much inventory if the quality of the existing version (θ) is low. Also, by comparing the optimal wholesale price of the upgraded product with the boundary value (Equation (C.4)), we get $\overline{w}_u(I) - w_u = \frac{\theta(\delta-1)(\eta\theta(\delta+1)-1)}{2}$, which does not depend on strategic inventories. From Equation (C.7), one can note that the demand for the upgraded product in the second period does not depend on SI. Previously, we found that (Equations (B.4) and (B.5)) the upper bound does not make any effect; the upper bound squeezes the manufacturer power to set high wholesale price due to inventory.

Lemma C.2 *The wholesale prices of the manufacturer in the second period are as follows:*

$$w_{2e}(I,\delta) = \begin{cases} \frac{\theta(1+\eta\theta-2I)}{2} & \textit{if } I < \overline{I}(\delta) \\ \overline{w}_{2e}, & \textit{otherwise} \end{cases}$$

$$w_u(I,\delta) = \frac{\theta(\delta+\delta^2\eta\theta-2I)}{2} \ \forall \ I$$

Therefore, substituting responses obtained in Equations (C.6) and (C.7) in Equation (9), the total profit function for the retailer in the first period is obtained as:

$$\pi_r(q_{1e},I,\delta) = \frac{16(q_{1e}\theta(1-q_{1e}) - hI - w_{1e}(I+q_{1e})) + \theta\left(\eta\delta\theta\left(\eta\theta\left(\delta^2+\delta-1\right)-2\delta\right)+\delta+4I(\eta\theta+3)-12I^2\right)}{16} \tag{C.8}$$

Because $\frac{\partial^2\pi_r}{\partial {q_{1e}}^2} = -2\theta < 0$, and $\frac{\partial^2\pi_r}{\partial {q_{1e}}^2}\cdot\frac{\partial^2\pi_r}{\partial I^2} - \left(\frac{\partial^2\pi_r}{\partial q_{1e}\partial I}\right)^2 = 3\theta^2 > 0$, therefore, the profit function for the retailer is concave in q_{1e} and I. Now solving first-order conditions for the profit function in Equation (C.8), the response for the retailer is obtained as follows:

$$\left.\begin{aligned} q_{1e}(w_{1e}) =& \frac{\theta - w_{1e}}{2\theta} \\ I(w_{1e}) =& \frac{\theta(3+\eta\theta)-4(w_{1e}+h)}{6\theta} \end{aligned}\right\} \tag{C.9}$$

It is intuitive that the volume of strategic inventories $\left(\frac{dI}{dw_{1e}} = -\frac{2}{3\theta} < 0\right)$ and selling quantities $\left(\frac{dI}{dw_{1e}} = -\frac{2}{3\theta} < 0\right)$ both decrease with respect to wholesale price, results also reflect that fact. If the wholesale price is too high, then the retailer might not buy products to carry forward in the first period and the retailer will purchase $Q_{1e}(w_{1e}) = q_{1e}(w_{1e}) + I(w_{1e}) = \frac{\theta(6+\eta\theta)-4h-7w_{1e}}{6\theta}$ amounts of product in the first period. And we obtain the maximum threshold of the first-period wholesale price for the existing product (by solving $I(w_{1e}) = 0$) as follows:

$$\overline{w}_{1e} = \frac{\theta(3+\eta\theta)-4h}{4} \tag{C.10}$$

However, the optimal volume of strategic inventories might exceed the upper bound; we found earlier $(\overline{I})$ if $w_{1e} < \hat{w}_{1e}(\delta) = \frac{\theta(3+\eta\theta(\delta-3))-4h}{4}$.

Lemma C.3 *The volume of strategic inventories carried by the retailer in the first period will be*

$$I(w_{1e}) = \begin{cases} \frac{\theta(3+\eta\theta)-4(w_{1e}+h)}{6\theta} & \text{if } w_{1e} < \hat{w}_{1e}(\delta) \\ 0, & \text{otherwise} \end{cases}$$

Finally, substituting Equations (C.9) and (C.6) in Equation (C.5), the total profit for the manufacturer in the first period is obtained as:

$$\pi_m(w_{1e},\delta) = \frac{16h^2 - \left(w_{1e} - \eta\theta^2\right)\left(59w_{1e} + 16h - 5\eta\theta^2 - 54\theta\right) + 9\left(\theta^2\delta\left(1 - \eta\theta\left(2\delta + \eta\theta\left(1 - \delta - \delta^2\right)\right)\right) - (w_{1e} - \theta)^2\right)}{54\eta\theta} \tag{C.11}$$

Because $\frac{d^2\pi_m}{dw_{1e}^2} = -\frac{17}{9\theta} < 0$, therefore, the manufacturer's profit function is concave. Solving the first order condition, we obtain the wholesale price in the first period as

$$w_{1e} = \frac{\theta(9 + 8\eta\theta) - 2h}{17} \tag{C.12}$$

Summarizing, we present the optimal response for Scenario EUI in Table 4. Note that the manufacturer can set the wholesale price higher than that obtained in Equation (C.10) if $\overline{w}_{1e} - w_{1e} > 0$, i.e., $h < h_1 = \frac{1}{4}\theta(1 - \eta\theta)$ or $\theta > \overline{\overline{\theta}} = \frac{1-\sqrt{1-16\eta h}}{2\eta}$. The threshold represents the maximum holding cost value until the retailer can maintain inventories while selling both products. Moreover, one can find that the manufacturer cannot offer the wholesale price below $\hat{w}_{1e}$, as $w_{1e} - \hat{w}_{1e} = \frac{3(20h+\theta(17\eta\delta\theta+5(1-\eta\theta)))}{68} > 0 \; \forall \; h \geq 0$. Therefore the manufacturer always offers such a wholesale price in the first period that the retailer may buy the existing product in both periods.

Lemma C.4 *The optimal wholesale price sets by the manufacturer for the first period are as follows:*

$$w_{1e} = \begin{cases} \frac{\theta(9+8\eta\theta)-2h}{17} & \text{if } h < h_1 \\ \frac{\theta(3+\eta\theta)-4h}{4}, & \text{otherwise} \end{cases}$$

The wholesale price should be high for the high quality of the existing version; the results also reflect that fact. If the holding cost is not too high ($h \leq h_1$), profit for the manufacturer become

$$\pi_m = \frac{3\eta(72h^2 + 47\theta^2(1 - 2\eta\theta) - 36h\theta(1 - \eta\theta)) + \theta(17 + 107\eta^3\theta^3)}{918\eta\theta} \tag{C.13}$$

One can verify that the manufacturer receives more profit by setting the product quality the same as that of the Scenario EUN instead of the product quality in Scenario UN (i.e., $\theta_u^{EUI} = \theta_u^{EUN}$) because $\pi_m^{EUI}(\theta_u^{EUN}) - \pi_m^{EUI}(\theta_u^{UN}) = \frac{\eta\theta^2(3-5\eta\theta)}{216} > 0$. Therefore, the manufacturer should set the quality level as θ_u^{EUN}, if an upgraded product is offered with the existing version. One can also verify that if the manufacturer sets the quality by optimizing the profit function in the decentralized scenario, it remains the same with θ_u^{EUN}.

C.2 Manufacturer offers only existing products in the second period:

In this scenario, the profit function of the retailer in the second period is obtained as follows:

$$\pi_{r2}(q_{2e}) = q_{2e}p_{2e} - (q_{2e} - I)w_{2e} \tag{C.14}$$

One can verify that the profit function in Equation (C.14) is concave because $\frac{d^2\pi_{r2}}{dq_{2e}{}^2} = -2\theta < 0$. Solving the first order condition, the selling quantity is obtained as follows:

$$q_{2e}(w_{2e}) = \frac{\theta - w_{2e}}{2\theta}; \tag{C.15}$$

The procured quantity, $Q_{2e} = q_{2e} - I = \frac{\theta(1-2I)-w_{2e}}{2\theta}$ in the second period decreases with the wholesale price. Therefore, if the manufacturer sets the wholesale price for the existing product above $\hat{w}_{2e}(I) = \theta(1 - 2I)$, then the retailer will not buy products.

Lemma C.5 *The selling quantity of the retailer in the second period will be*

$$q_{2e}(w_{2e}, w_u, \delta) = \begin{cases} q_{2e}p_{2e} - (q_{2e} - I)w_{2e} \ \ \textit{if } w_{2e} < \hat{w}_{2e}(I) \\ I, \ \ \textit{otherwise} \end{cases}$$

Next by using the response obtained in Equation (C.15), the profit function for the manufacturer becomes:

$$\pi_{m2}(w_{2e}) = \frac{(w_{2e} - \eta\theta^2)(\theta(1 - 2I) - w_{2e})}{2\theta} \tag{C.16}$$

Because $\frac{d^2\pi_{m2}}{dw_{2e}{}^2} = -\frac{1}{\theta} < 0$, the profit function for the manufacturer is concave. By solving the first-order condition, the wholesale price for the existing product in the second period is obtained as follows:

$$w_{2e}(I) = \frac{\theta(1 - 2I + \eta\theta)}{2} \tag{C.17}$$

Using Equation (C.17), the order quantity is obtained as $Q_{2e} = \frac{1-2I+\eta\theta}{4}$, which is positive if $I < \frac{1-\eta\theta}{2}$. A similar upper threshold of inventories (I) is also obtained by solving $w_{2e}(I) = \hat{w}_{2e}(I)$.

Lemma C.6 *The wholesale price of the manufacturer in the second period will be*

$$w_{2e}(I) = \begin{cases} \frac{\theta(1-2I+\eta\theta)}{2} \ \ \textit{if } I < \frac{1-\eta\theta}{2} \\ \hat{w}_{2e}(I), \ \ \textit{otherwise} \end{cases}$$

Substituting responses obtained in Equations (C.17) and (C.15) in Equation (C.14), the profit function of the retailer in the first period is obtained as follows:

$$\pi_r(q_{1e}, I) = q_{1e}(p_{2e} - w_{1e}) - (w_{1e} + h)I + \pi_{r2}(I) \tag{C.18}$$

The profit function given by Equation (C.18) for the retailer is concave in q_{1e} and I, because $\frac{\partial^2 \pi_r}{\partial {q_{1e}}^2} = -2\theta < 0$, and $\frac{\partial^2 \pi_r}{\partial {q_{1e}}^2} \cdot \frac{\partial^2 \pi_r}{\partial I^2} - \left(\frac{\partial^2 \pi_r}{\partial q_{1e} \partial I}\right)^2 = 3\theta^2 > 0$. Therefore, solving first-order conditions, the responses for the retailer are obtained as:

$$\left.\begin{aligned} q_{1e}(w_{1e}) =& \frac{\theta - w_{1e}}{2\theta} \\ I(w_{1e}) =& \frac{(3+\eta\theta)\theta - 4(h + w_{1e})}{6\theta} \end{aligned}\right\} \tag{C.19}$$

Once again, the amount of strategic inventories decreases with respect to wholesale price because $\frac{dI(w_{1e})}{dw_{1e}} = -\frac{2}{3\theta} < 0$, therefore, the manufacturer can set the maximum wholesale price as given below:

$$\overline{\overline{w}}_{1e} = \frac{\theta(3+\eta\theta) - 4h}{4} \tag{C.20}$$

Therefore, if $w_{1e} > \overline{\overline{w}}_{1e}$, then the retailer does not hold strategic inventories and sells only the existing version in the second period. Also, one can find that $I(w_{1e}) > \frac{1-\eta\theta}{2}$ if $w_{1e} < \eta\theta^2 - h$, i.e., if $w_{1e} < \eta\theta^2 - h$ the retailer does not purchase any product in the second period.

Lemma C.7 *The volume of inventories carried by the retailer in the first period will be*

$$I(w_{1e}) = \begin{cases} \frac{\theta(3+\eta\theta) - 4(w_{1e}+h)}{6\theta} & \textit{if } w_{1e} < \overline{\overline{w}}_{1e} \\ 0, & \textit{otherwise} \end{cases}$$

Using the responses obtained in Equations (C.19) and (C.17) in Equation (C.16), the total profit for the manufacturer in the first period is obtained as:

$$\pi_m(w_{1e}) = \frac{4h^2 + (w_{1e} - \eta\theta^2)(\theta(18 - \eta\theta) - 4h - 17w_{1e})}{18\theta} \tag{C.21}$$

Because $\frac{d^2\pi_m}{dw_{1e}^2} = -\frac{17}{9\theta} < 0$, the manufacturer's profit function is concave. Solving the first-order condition for the profit function in Equation (C.21), we obtain the wholesale price in Scenario EI as follows:

$$w_{1e} = \frac{\theta(9 + 8\eta\theta) - 2h}{17} \tag{C.22}$$

By using back substitution, the optimal response in Scenario EI is obtained and presented in Table 4. Once again, the wholesale price in Equation (C.22) must satisfy $\overline{\overline{w}}_{1e} - w_{1e} > 0$, i.e. $h < h_1 = \frac{\theta(1-\eta\theta)}{4}$. If the holding cost is too high ($h > h_1$), the retailer does not retain inventories, leading to Scenario EN. One can find that if $\theta = 1$ and $\eta = 0$, i.e., if we normalize the product quality and ignore the per unit production cost as considered by Anand et al. (2008), then $h_1 = \frac{1}{4}$. One can also find that $w_{1e} - (\eta\theta^2 - h) = \frac{3(3\theta(1-\eta\theta)+5h)}{17} > 0 \ \forall h > 0$. Therefore, the manufacturer does not offer such a wholesale price that the retailer does not purchase any product in the second period.

Lemma C.8 *The optimal wholesale price set by the manufacturer for the first period will be*

$$w_{1e} = \begin{cases} \frac{\theta(9+8\eta\theta)-2h}{17} & \text{if } h < h_1 \\ \frac{\theta(3+\eta\theta)-4h}{4}, & \text{otherwise} \end{cases}$$

One can find that if the manufacturer sets the boundary wholesale price $\overline{\overline{w}}_{1e}$, then the retailer does not carry inventories. But the manufacturer does not offer such wholesale price because in that scenario, the profit of the manufacturer $\left(\pi_m^{EN^*} = \frac{8\theta^2(1-\eta\theta)^2-(\theta(1-\eta\theta)-4h)^2}{32\theta}\right)$ is less $(\pi_m^{EN} - \pi_m^{EN^*} = \frac{(\theta(1-\eta\theta)+4h)^2}{32\theta} > 0 \; \forall \; h > 0)$.

C.3 Manufacturer offers only upgraded product in the second period:

In this case, the manufacturer offers an existing version in the first period and an upgraded version in the second period, and the retailer may or may not carry inventories from the first period. Therefore, if the retailer holds inventories of the existing product from the first period, then from Equations (1) and (5), we obtain the inverse demand functions for the first and second periods, respectively, as

$$\begin{aligned} p_{1e}(q_{1e}) =&(1-q_{1e})\theta \\ p_{2e}(q_u, I) =&(1-q_u-I)\theta \\ p_u(q_u, I) =&(\delta(1-q_u)-I)\theta \end{aligned} \tag{C.23}$$

Therefore, the profit function of the retailer in the second period is as follows:

$$\pi_{r2} = Ip_{2e} + q_u(p_u - w_u) \tag{C.24}$$

The profit function in Equation (C.24) is concave because $\frac{d^2\pi_{r2}}{dq_u{}^2} = -2\delta\theta < 0$ and we obtain the selling quantity for the upgraded product by solving the first-order condition as follows:

$$q_u(w_u, \delta, I) = Q_u(w_u, \delta, I) = \frac{(\delta-2I)\theta - w_u}{2\delta\theta} \tag{C.25}$$

Once again, the order quantity in Equation (C.25) decreases with the wholesale price, and the retailer cannot buy any product in the second period if the manufacturer sets a wholesale price above the threshold $w_u = \hat{w}_u(I, \delta) = (\delta - 2I)\theta$.

Lemma C.9 *The selling quantity of the upgraded product in the second period will be*

$$q_u(w_{2e}, w_u, \delta) = \begin{cases} \frac{(\delta-2I)\theta-w_u}{2\delta\theta} & \text{if } w_u < \hat{w}_u(I,\delta) \\ 0, & \text{otherwise} \end{cases}$$

Using the response given in Equation (C.25), the profit function for the manufacturer becomes

$$\pi_{m2}(w_u,\delta) = \frac{((\delta-2I)\theta - w_u)\left(w_u - \eta\theta^2\delta^2\right)}{2\delta\theta} \tag{C.26}$$

The profit function in Equation (C.26) is concave because $\frac{\partial^2\pi_{m2}}{\partial {w_u}^2} = -\frac{1}{\delta\theta} < 0$, therefore solving first-order conditions, the wholesale price for the upgraded product in the second period is obtained as:

$$w_u(I,\delta) = \frac{\theta\left(\delta(1+\eta\delta\theta) - 2I\right)}{2} \tag{C.27}$$

The order quantity in this scenario is $Q_u(I,\delta) = q_u(I,\delta) = \frac{\delta(1-\eta\delta\theta)-2I}{4\delta} > 0$ if $I < \hat{I}(\delta) = \frac{\delta(1-\eta\delta\theta)}{2}$. It can also be observed that if $I < \hat{I}(\delta)$ then $\hat{w}_u(I,\delta) > w_u(I,\delta)$. Therefore, if $I > \hat{I}(\delta)$, the retailer will not purchase any product in the second period.

Lemma C.10 *The wholesale price of the upgraded product in the second period will be*

$$w_u(I,\delta) = \frac{\theta\left(\delta(1+\eta\delta\theta) - 2I\right)}{2} \;\; \textit{if } I < \hat{I}(\delta)$$

Substituting the response obtained in Equations (C.25) and (C.27) in Equation (C.24), the total profit for the retailer is obtained as:

$$\pi_r(q_{1e},I,\delta) = \frac{16\delta(s_{1e}(\theta-\theta s_{1e}-w_{1e}) - (w_{1e}+h)I) + \theta\left(4I^2(1-4\delta) + 4I\delta(3+\eta\delta\theta) + \delta^2(1-\eta\delta\theta)^2\right)}{16\delta} \tag{C.28}$$

The profit function for the retailer given in Equation (C.28) is concave in q_{1e} and I, because $\frac{\partial^2\pi_r}{\partial {q_{1e}}^2} = -2\theta < 0$, and $\frac{\partial^2\pi_r}{\partial {q_{1e}}^2}\cdot\frac{\partial^2\pi_r}{\partial I^2} - \left(\frac{\partial^2\pi_r}{\partial q_{1e}\partial I}\right)^2 = \frac{\theta^2(4\delta-1)}{\delta} > 0$, respectively. By solving the first order conditions, the response for the retailer is obtained as follows:

$$\left.\begin{aligned} q_{1e}(w_{1e},\delta) =& \frac{\theta - w_{1e}}{2\theta} \\ I(w_{1e},\delta) =& \frac{\delta\left(3\theta + \eta\delta\theta^2 - 4(w_{1e}+h)\right)}{2\theta(4\delta-1)} \end{aligned}\right\} \tag{C.29}$$

Similar to the previous scenario, the volume of inventories decreases with respect to wholesale price because $\frac{dI(w_{1e},\delta)}{dw_{1e}} = -\frac{2\delta}{\theta(4\delta-1)} < 0$, therefore, the retailer holds product strategically to sell in the second period if $w_{1e} < \tilde{w}_{1e}(\delta) = \frac{\theta(3+\eta\delta\theta)-4h}{4}$. Consequently, if $w_{1e} > \tilde{w}_{1e}$, the retailer does not retain strategic inventories and purchases only an upgraded product in the second period. It is found that $I > \hat{I}$ if $w_{1e} < \underline{\underline{w}}_{1e} = \theta + \delta\theta(\eta\delta\theta - 1) - h$. Therefore, the retailer retains high inventories and does not procure any product in the second period if $w_{1e} < \underline{\underline{w}}_{1e}$.

Lemma C.11 *The amount of inventories carried by the retailer in the first period will be*

$$I(w_{1e}) = \begin{cases} \frac{\delta\left(3\theta+\eta\delta\theta^2-4(w_{1e}+h)\right)}{2\theta(4\delta-1)} & \textit{if } w_{1e} < \tilde{w}_{1e} \\ 0, & \textit{otherwise} \end{cases}$$

Substituting responses obtained from Equations (C.29) and (C.27) in Equation (C.26), the total profit for the manufacturer in the first period is obtained as:

$$\pi_m(w_{1e},\delta) = \frac{4\delta(h+w_{1e}-\theta(1-\delta+\delta^2\eta\theta))^2-(4\delta-1)(w_{1e}-\eta\theta^2)(4h\delta+(8\delta-1)w_{1e}+\theta-\delta\theta(7+\eta\delta\theta))}{2(4\delta-1)^2} \tag{C.30}$$

Because $\frac{d^2\pi_m}{dw_{1e}^2} = -\frac{1+16(2\delta-1)\delta}{\theta(4\delta-1)^2} < 0$, the profit function is concave. Solving the first order condition, the wholesale price is obtained as:

$$w_{1e} = \frac{\theta(1+\eta\theta-\delta(19-36\delta+(12-(31-4\delta)\delta)\eta\theta))-4h(4\delta-3)\delta}{2(1+16\delta(2\delta-1))} \tag{C.31}$$

We present optimal responses of the Scenario UI for $\theta_u^{UI} = \theta_u^{UN} = \frac{1}{3\eta\theta}$ in Table 4. Noted that the wholesale price must satisfy $w_{1e} < \tilde{w}_{1e}$, i.e. if $h < h_2 = \frac{\theta(14-3\eta\theta(10-3\eta\theta))}{18(2-\eta\theta)}$ for θ_u^{UN}. Also, at h_2, the amount of inventories becomes zero. Consequently, the retailer sells only the upgraded product in the second period if $h \geq h_2$, which leads to Scenario UN. One can also verify that $w_{1e} > \underline{\underline{w}}_{1e}\ \forall\ \theta \in (0, \frac{1}{3\eta})$. This indicates that the manufacturer does not set such a wholesale price that the retailer will not purchase any product in the second period.

Lemma C.12 *The optimal wholesale price set by the manufacturer for the first period will be*

$$w_{1e} = \begin{cases} \frac{\theta(1+\eta\theta-\delta(19-36\delta+(12-(31-4\delta)\delta)\eta\theta))-4h(4\delta-3)\delta}{2(1+16\delta(2\delta-1))} & \text{if } h < h_2 \\ \frac{\theta(3+\eta\theta)-4h}{4} & \text{otherwise} \end{cases}$$

Similar to Subsection C.2, one can find that the manufacturer does not benefit by offering the boundary wholesale price $\tilde{w}_{1e}$.

D Proof of Propositions 1, 2 and 3

D.1 Proof of Proposition 1

Comparing profits as presented in Table 3, we obtain the following relations:
$\pi_m^{EUN} - \pi_m^{EN} = \frac{(1-2\eta\theta)^3}{27\eta} > 0$; $\pi_m^{EUN} - \pi_m^{UN} = \frac{\theta(3(1-3\eta\theta)+(3-5\eta\theta)\eta\theta)}{216} > 0$; $\pi_m^{EDN} - \pi_m^{EN} = \frac{\eta^2\theta^3}{32} > 0$; $\pi_m^{UN} - \pi_m^{EN} = \frac{(1-3\eta\theta)^2(4-3\eta\theta)}{216\eta} > 0$; $\pi_m^{EUN} - \pi_m^{EDN} = \frac{16-\eta\theta(96-\eta\theta(192-155\eta\theta))}{864\eta} > 0$ if $\theta \leq \frac{2(32+9\times 2^{\frac{1}{3}}-12\times 2^{\frac{2}{3}})}{155\eta} = \overline{\theta}$.

D.2 Proof of Proposition 2

The difference between the manufacturer's profits in the presence of strategic inventories are as follows:

$\pi_m^{EUI} - \pi_m^{EI} = \frac{(1-2\eta\theta)^3}{54\eta} > 0$

$\pi_m^{EUI} - \pi_m^{EDI} = \frac{16-\eta\theta(96-\eta\theta(192-155\eta\theta))}{864\eta} > 0$ if $\theta \leq \frac{2(32+9\times 2^{\frac{1}{3}}-12\times 2^{\frac{2}{3}})}{155\eta} = \overline{\theta}$

$\pi_m^{EUI} - \pi_m^{UI} = \frac{432h^2(1-3\eta\theta)(47-6\eta\theta)-72\theta h(1-3\eta\theta)(22-3\eta\theta(53-6\eta\theta))-\theta^2(108-\eta\theta(1704-\eta\theta(2819+3\eta\theta(134+93\eta\theta))))}{3672\theta(32-3\eta\theta(16-3\eta\theta))} > 0$

if $h \geq \frac{(66-27\eta\theta(25-\eta\theta(55-6\eta\theta))+\sqrt{51(1-3\eta\theta)(32-3\eta\theta(16-3\eta\theta))(12-\eta\theta(177-\eta\theta(253-30\eta\theta)))})\theta}{36(1-3\eta\theta)(47-6\eta\theta)} = h_3$

One can find that h_3 is valid if $\theta \in (0, \ddot{\theta})$ where $\ddot{\theta}$ is the real positive root of the equation $66 - 27\eta\theta(25 - \eta\theta(55 - 6\eta\theta)) + \sqrt{51(1 - 3\eta\theta)(32 - 3\eta\theta(16 - 3\eta\theta))(12 - \eta\theta(177 - \eta\theta(253 - 30\eta\theta)))} = 0$.

D.3 Proof of Proposition 3

The proof of Proposition 3 is obtained from the proof of Propositions 1 and 2 along with the following difference between manufacturer's profit:

$\pi_m^{EUI} - \pi_m^{EUN} = \pi_m^{EDI} - \pi_m^{EDN} = \frac{(\theta(1-\eta\theta)+4h)^2}{68\theta} > 0$

$\pi_m^{UI} - \pi_m^{UN} = \frac{\theta^2(17-3\eta\theta(22-21\eta\theta))-6\theta h(10-3\eta\theta(5+3\eta\theta))+36h^2(1+3\eta\theta)}{18\theta(32-3\eta\theta(16-3\eta\theta))} > 0$

$\pi_m^{EI} - \pi_m^{EN} = \frac{(\theta(1-\eta\theta)-4h)^2}{68\theta} > 0$.

E Comparison and nature of wholesale and retail prices

Table E.1: Comparison of wholesale and retail prices

Wholesale price	Retail price
$w_u^{EUN} - w_{2e}^{EUN} = \frac{2(1+\eta\theta)(1-2\eta\theta)}{9\eta} > 0$ $w_{2e}^{EDN} - w_d^{EDN} = \frac{\theta(2+3\eta\theta)}{8} > 0$	$p_u^{EUN} - p_{2e}^{EUN} = \frac{(1-2\eta\theta)(5+2\eta\theta)}{18\eta} > 0$ $p_{2e}^{EDN} - p_d^{EDN} = \frac{3\theta(2+\eta\theta)}{16} > 0$
$w_{1e}^{EUI} - w_{2e}^{EUI} = \frac{3(\theta(1-\eta\theta)+4h)}{17} > 0$ $w_{1e}^{EDI} - w_{2e}^{EDI} = \frac{3(\theta(1-\eta\theta)+4h)}{17} > 0$	$p_{1e}^{EUI} - p_{2e}^{EUI} = \frac{3(\theta(1-\eta\theta)+4h)}{34} > 0$ $p_{1e}^{EDI} - p_{2e}^{EDI} = \frac{3(\theta(1-\eta\theta)+4h)}{34} > 0$
$w_u^{EUI} - w_{2e}^{EUI} = \frac{2(1+\eta\theta)(1-2\eta\theta)}{9\eta} > 0$ $w_{2e}^{EDI} - w_d^{EDI} = \frac{\theta(24+61\eta\theta)+40h}{136} > 0$ -	$p_u^{EUI} - p_{2e}^{EUI} = \frac{(1-2\eta\theta)(5+2\eta\theta)}{18\eta} > 0$ $p_{2e}^{EDI} - p_u^{EDI} = \frac{40h+\theta(92+61\eta\theta)}{272}$ $p_u^{UI} - p_{2e}^{UI} = \frac{(1-3\eta\theta)(160-9\eta(6h(2-\eta\theta)+\theta(2+\eta\theta)(11-3\eta\theta)))}{18\eta(32-3\eta\theta(16-3\eta\theta)))}$

The graphical representation of second period wholesale prices in all scenarios is as follows:

Table E.2: Nature of wholesale and retail price with respect to θ

Wholesale price	Retail price
$\frac{dw_u^{EUN}}{d\theta} = \frac{5+2\eta\theta}{18} > 0$ $\frac{dw_d^{EDN}}{d\theta} = \frac{1+\eta\theta}{4} > 0$ $\frac{dw_d^{UN}}{d\theta} = 0$	$\frac{dp_u^{EUN}}{d\theta} = \frac{11+2\eta\theta}{36} > 0$ $\frac{dp_d^{EDN}}{d\theta} = \frac{3+\eta\theta}{8} > 0$ $\frac{dp_d^{UN}}{d\theta} = 0$
$\frac{dw_u^{EUI}}{d\theta} = \frac{2(10+31\eta\theta)}{153} > 0$ $\frac{dw_d^{EDI}}{d\theta} = \frac{3(4+9\eta\theta)}{68} > 0$ $\frac{dw_u^{UI}}{d\theta} = -\frac{448-3\eta\theta(640-726\eta\theta+288\eta^2\theta^2-27\eta^3\theta^3)-18\eta(64-36\eta\theta+9\eta^2\theta^2)}{3(32-3\eta\theta(16-3\eta\theta))^2} < 0$ if $h < \hat{h} = \frac{448-3\eta\theta(640-726\eta\theta+288\eta^2\theta^2-27\eta^3\theta^3)}{18\eta(64-36\eta\theta+9\eta^2\theta^2)}$	$\frac{dp_u^{EUI}}{d\theta} = \frac{71+62\eta\theta}{306} > 0$ $\frac{dp_d^{EDI}}{d\theta} = \frac{46+27\eta\theta}{136} > 0$ $\frac{dp_u^{UI}}{d\theta} = -\frac{448-3\eta\theta(640-726\eta\theta+288\eta^2\theta^2-27\eta^3\theta^3)-18\eta(64-36\eta\theta+9\eta^2\theta^2)}{6(32-3\eta\theta(16-3\eta\theta))^2} < 0$ if $h < \hat{h} = \frac{448-3\eta\theta(640-726\eta\theta+288\eta^2\theta^2-27\eta^3\theta^3)}{18\eta(64-36\eta\theta+9\eta^2\theta^2)}$

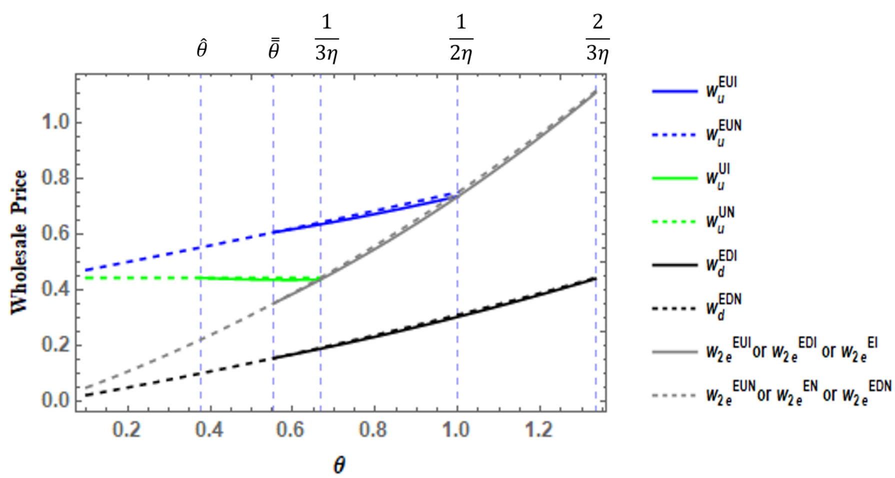

Figure E.1: Second period wholesale prices in all scenarios: $h = 0.1$, $\eta = 0.5$, $\theta \in (0, \frac{2}{3\eta})$, $\bar{\bar{\theta}} : I^{EI} = 0$ and $\hat{\theta} : I^{UI} = 0$.

F The manufacturer introduces only a downgraded version (Scenarios DI and DN)

The derivation for optimal decision in Scenarios DI and DN are similar to Scenarios UI and UN, respectively. Therefore, we omitted the derivations. Also, the optimal response for Scenario DN is identical to Scenario UN. The key difference between Scenarios UN and DN is that Scenario DN is valid if $\theta \geq \frac{1}{3\eta}$. The optimal response in Scenario DI is presented in the following lemma:

Lemma F.1 $w_{1e}^{DI} = \frac{\theta(5-9\eta(17\theta-12(h-4h\eta\theta+\eta\theta^2(7+8\eta\theta))))}{6(1-48\eta\theta(1-6\eta\theta))}$; $q_{1e}^{DI} = \frac{1-27\eta(4h(1-4\eta\theta)+\theta(5-4\eta\theta(9-8\eta\theta)))}{12(1-48\eta\theta(1-6\eta\theta))}$;
$p_{1e}^{DI} = \frac{\theta(11-9\eta(49\theta-12(h-4h\eta\theta+\eta\theta^2(23+8\eta\theta))))}{3(1-48\eta\theta(1-6\eta\theta))}$; $I^s = q_{2e}^{DI} = \frac{1+18h\eta(1-18\eta\theta)-3\eta\theta(13-3\eta\theta(25-24\eta\theta))}{3(1-48\eta\theta(1-6\eta\theta))}$;
$p_{2e}^{DI} = \frac{(7\theta+6h)(1-6\eta\theta)(1-18\eta\theta)-9\eta\theta^2(7+6\eta\theta)(1-8\eta\theta)}{6(1-48\eta\theta(1-6\eta\theta))}$; $w_d^{DI} = \frac{1-18h\eta(1-18\eta\theta)-3\eta\theta(19-9\eta\theta(13+8\eta\theta))}{9(1-48\eta\theta(1-6\eta\theta))}$;
$q_d^{DI} = \frac{3\eta(h(36\eta\theta-2)+\theta(\eta\theta(7+24\eta\theta))-1)}{2(1-48\eta\theta(1-6\eta\theta))}$; $p_d^{DI} = \frac{4+18h\eta(18\eta\theta-1)-3\eta\theta(67-9\eta\theta(45+8\eta\theta))}{18\eta(1-48\eta\theta(1-6\eta\theta))}$; $\delta_d^{DI} = \frac{1}{3\eta\theta}$;
$\pi_r^{DI} = \frac{\Psi_7}{144(1-48\eta\theta(1-6\eta\theta))^2}$; $\pi_m^{DI} = \frac{\Psi_8}{72(1-48\eta\theta(1-6\eta\theta))}$;

Where $\Psi_7 = 432h^2\eta(60\eta\theta-1)(1+3\eta\theta(24\eta\theta-5)) - 24h(2-3\eta\theta(43-9\eta\theta(731212\eta\theta(53-16\eta\theta(13-12\eta\theta))))) - \theta(7+9\eta\theta(34-\eta\theta(4313-12\eta\theta(4919-72\eta\theta(307-8\eta\theta(53-24\eta\theta))))))$*;* $\Psi_8 = 432h^2\eta(1+3\eta\theta)+72h\eta\theta(11-3\eta\theta(23-24\eta\theta))+\theta(25-3\eta\theta(314-3\eta\theta(769-48\eta\theta(25-12\eta\theta))))$.

One can find that product quality in Scenario DN must be lower compared to the existing version ($\delta_d^{DN} < 1$) if $\theta > \frac{1}{3\eta}$. To characterize the nature of optimal product quality when only the downgraded product is offered along with others, we proposed the following lemma:

Lemma F.2 *Given the existing product quality level* θ*, the quality level of the newly introduced product satisfies the following relations*

- *If* $\theta \in (\frac{1}{3\eta}, \frac{1}{2\eta})$*, the product qualities satisfy* $\theta_u^{EUN} \geq \theta_e^{EN} \geq \theta_d^{DN} \geq \theta_d^{EDN}$
- *If* $\theta \in (\frac{1}{2\eta}, \frac{2}{3\eta})$*, the product qualities satisfy* $\theta_e^{EN} \geq \theta_d^{DN} \geq \theta_d^{EDN}$
- *If* $\theta \in (\frac{2}{3\eta}, \frac{1}{\eta})$*, the product qualities satisfy* $\theta_e^{EN} \geq \theta_d^{DN}$*.*

It is noted from Lemma F.1 that while the manufacturer offers only a downgraded product, the retailer carries strategic inventories of the existing product if $h \leq h_4 = \frac{3\eta\theta(13-3\eta\theta(25-24\eta\theta))-1}{18\eta(18\eta\theta-1)}$, and the wholesale price and retail price increase with earlier version product quality, $\frac{dw_d^{DI}}{d\theta} = 2\frac{dp_d^{DI}}{d\theta} = \frac{2\eta\theta(7+12\eta\theta-1152\eta^2\theta^2+3456\eta^3\theta^3)-1-12\eta(5-96\eta\theta+864\eta^2\theta^2)}{(1-48\eta\theta(1-6\eta\theta))^2} > 0$ if $h < \ddot{h} = \frac{2\eta\theta(7+12\eta\theta-1152\eta^2\theta^2+3456\eta^3\theta^3)-1}{12\eta(5-96\eta\theta+864\eta^2\theta^2)}$. Similar to Propositions 1 - 2, the following lemmas represent the profit maximization equilibrium when the introduction of a downgraded version is also a possibility.

Lemma F.3 *If the manufacturer introduces an upgraded or downgraded product in the second period and the retailer does not carry inventory, then the manufacturer's profit-maximizing equilibrium is*

$$S = \begin{cases} EUN & \text{if } 0 < \theta \leq \overline{\theta} \equiv \frac{2(32+9\cdot\sqrt[3]{2}-12\cdot\sqrt[3]{4})}{155\eta} \sim \frac{0.3134}{\eta} \\ EDN & \text{if } \overline{\theta} < \theta \leq \frac{2}{3\eta} \\ DN & \text{if } \frac{2}{3\eta} < \theta \leq \frac{1}{\eta} \end{cases}$$

Proof: The proof of the above lemma follows from Section D.1 and the following relations: $\pi_m^{DN} - \pi_m^{EN} = \frac{(1-3\eta\theta)^2(4-3\eta\theta)}{216\eta} > 0$; $\pi_m^{EDN} - \pi_m^{DN} = \frac{(2-3\eta\theta)^2(15\eta\theta-4)}{432\eta} > 0$.

Lemma F.4 *For any holding cost and optimal wholesale prices, when a manufacturer introduces an upgraded or a downgraded product and the retailer carries inventories, the manufacturer's optimal strategy is as follows:*

1. *If* $0 < \theta \leq \ddot{\theta}$ $\quad (0 \leq h_3 < h_1 < h_2)$

$$S = \begin{cases} UI & \text{if } 0 < h \leq h_3 \bigcup h_1 < h \leq h_2 \\ EUI & \text{if } h_3 < h \leq h_1 \end{cases}$$

2. *If* $\ddot{\theta} < \theta \leq \overline{\theta}$ $\quad (0 < h_1 < h_2)$

$$S = \begin{cases} EUI & \text{if } 0 < h \leq h_1 \\ UI & \text{if } h_1 < h \leq h_2 \end{cases}$$

3. *If* $\overline{\theta} < \theta \leq \frac{1}{3\eta}$ $\quad (0 < h_1 < h_2)$

$$S = \begin{cases} EDI & \text{if } 0 < h \leq h_1 \\ UI & \text{if } h_1 < h \leq h_2 \end{cases}$$

4. *If* $\frac{1}{3\eta} < \theta \leq \frac{2}{3\eta}$

$$S = \begin{cases} EDI & \text{if } 0 < h \leq h_1 \\ DI & \text{if } h_1 < h \leq h_4 \end{cases}$$

5. *If* $\frac{2}{3\eta} < \theta \leq \frac{1}{\eta}$

$$S = \begin{cases} DI & \text{if } 0 < h \leq h_4 \\ EI & \text{if } h_4 < h \leq h_1 \end{cases}$$

Proof: The proof of the above lemma follows from Section D.2 and the following relations:
$\pi_m^{EDI} - \pi_m^{DI} = \frac{27\eta^2\theta^4(1055-6912h\eta-48\eta\theta(63-50\eta\theta))+24\eta(6012h\eta-31)\theta^3+4(72h\eta(846h\eta-89)-101)\theta^2+576h(h(2-147\eta\theta)-\theta)}{4896\theta(1-48\eta\theta(1-6\eta\theta))} > 0$
$\forall h \in (0, h_1)$ and $\forall \theta \in (\frac{1}{3\eta}, \frac{2}{3\eta})$.
Finlay considering the Scenarios DI and DN, we restate Proposition F.5 as the follows:

Lemma F.5 *For any holding cost and optimal wholesale prices, when a manufacturer considers introducing an upgraded or downgraded product and the retailer may carry inventories, the manufacturer's optimal strategy is as follows:*

1. *If* $0 < \theta \leq \ddot{\theta}$

$$S = \begin{cases} UI & \text{if } 0 < h \leq h_3 \\ EUI & \text{if } h_3 < h \leq h_1 \\ EUN & \text{if } h_1 < h \end{cases}$$

2. *If* $\ddot{\theta} < \theta \leq \overline{\theta}$

$$S = \begin{cases} EUI & \text{if } 0 < h \leq h_1 \\ EUN & \text{if } h_1 < h \end{cases}$$

3. *If* $\overline{\theta} < \theta \leq \frac{2}{3\eta}$

$$S = \begin{cases} EDI & \text{if } 0 < h \leq h_1 \\ EDN & \text{if } h_1 < h \end{cases}$$

4. *If* $\frac{2}{3\eta} < \theta \leq \frac{1}{\eta}$

$$S = \begin{cases} DI & \text{if } 0 < h \leq h_5 \\ DN & \text{if } h_5 < h \end{cases}$$

where, $h_5 = \frac{(9\eta\theta(1-\eta\theta)-2)(48\eta\theta(6\eta\theta-1)+1)^{3/2}-216\eta^3\theta^3+207\eta^2\theta^2-33\eta\theta}{36\eta(1+3\eta\theta)(1+48\eta\theta(6\eta\theta-1))}$.

Proof: The proof of the above lemma follows from the proof of Lemmas D.2, F.4 and the following relations:
$\pi_m^{DI} - \pi_m^{DN} = \frac{324\eta^2(1+3\eta\theta)h^2+54\eta^2\theta(11-3\eta\theta(23-24\eta\theta))h+(6\eta\theta-1)(1-54\eta\theta+333\eta^2\theta^2-594\eta^3\theta^3+324\eta^4\theta^4)}{54\eta(1+48\eta\theta(6\eta\theta-1)))} > 0$
$\forall h > \frac{(9\eta\theta(1-\eta\theta)-2)(48\eta\theta(6\eta\theta-1)+1)^{3/2}-216\eta^3\theta^3+207\eta^2\theta^2-33\eta\theta}{36\eta(1+3\eta\theta)(1+48\eta\theta(6\eta\theta-1))} = h_5$.

G Thresholds of holding cost and existing product's quality, and their implications:

Table G.1: Thresholds of holding cost (h) and existing product's quality (θ) and their implication:

Limit (h)	Expression
$h_1(I^{EUI}/I^{EDI}/I^{EI}=0)$	$\frac{\theta(1-\eta\theta)}{4}$
$h_2(I^{UI}=0)$	$\frac{\theta(14-3\eta\theta(10-3\eta\theta))}{18(2-\eta\theta)}$
$h_3(\pi_m^{EUI}=\pi_m^{UI})$	$\frac{(66-27\eta\theta(25-\eta\theta(55-6\eta\theta))+\sqrt{51(1-3\eta\theta)(32-3\eta\theta(16-3\eta\theta))(12-\eta\theta(177-\eta\theta(253-30\eta\theta)))})\theta}{36(1-3\eta\theta)(47-6\eta\theta)}$
$h_4(I^{DI}=0)$	$\frac{3\eta\theta(13-3\eta\theta(25-24\eta\theta))-1}{18\eta(18\eta\theta-1)}$
$h_5(\pi_m^{DI}=\pi_m^{DN})$	$\frac{(9\eta\theta(1-\eta\theta)-2)(48\eta\theta(6\eta\theta-1)+1)^{3/2}-216\eta^3\theta^3+207\eta^2\theta^2-33\eta\theta}{36\eta(1+3\eta\theta)(1+8\eta\theta(6\eta\theta-1))}$
$\hat{h}(\frac{dw_u^{UI}}{d\theta}=2\frac{dp_u^{UI}}{d\theta}>0)$	$\frac{448-3\eta\theta(640-726\eta\theta+288\eta^2\theta^2-27\eta^3\theta^3)}{18\eta(64-36\eta\theta+9\eta^2\theta^2)}$
$\ddot{h}(\frac{dw_u^{DI}}{d\theta}=2\frac{dp_u^{DI}}{d\theta}>0)$	$\frac{2\eta\theta(7+12\eta\theta-1152\eta^2\theta^2+3456\eta^3\theta^3)-1}{12\eta(5-96\eta\theta+864\eta^2\theta^2)}$
Limit (θ)	Expression
$\overline{\theta}(\pi_m^{EUI}-\pi_m^{EDI})$	$\frac{2(32+9\cdot\sqrt[3]{2}-12\cdot\sqrt[3]{4})}{155\eta}\sim\frac{0.3134}{\eta}$
$\overline{\overline{\theta}}(I^{EI}=0)$	$\frac{1-\sqrt{1-16\eta h}}{2\eta}$
$\hat{\theta}(I^{UI}=0)$	The positive root of the cubic equation $9\eta^2\theta^3-30\eta\theta^2+2(7+9h\eta)\theta-36h=0$
$\ddot{\theta}(h_3=0)$	The real positive root of the equation $66-27\eta\theta(25-\eta\theta(55-6\eta\theta))+\sqrt{51(1-3\eta\theta)(32-3\eta\theta(16-3\eta\theta))(12-\eta\theta(177-\eta\theta(253-30\eta\theta)))}=0$

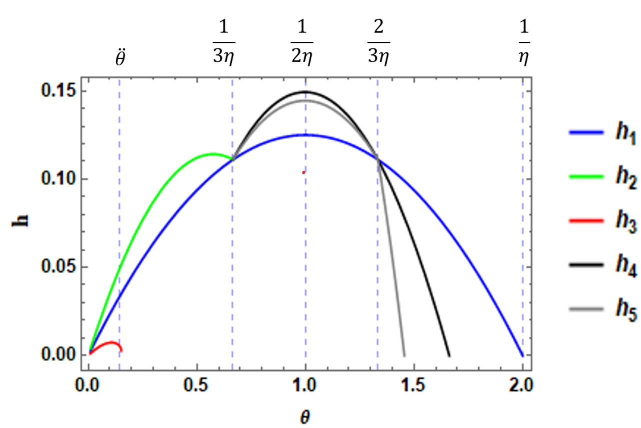

Figure G.1: Holding cost thresholds: $\theta\in(0,\frac{1}{\eta})$, $\eta=0.5$

Supplementary file for "On the Interdependence of Strategic Inventories and New Product Generation Introduction" containing the detailed derivations of optimal decisions when the manufacturer determines product quality in the first period.

S1 Quality is determined and disclosed in the first period

Thus far, we assumed that the manufacturer determines the quality in the second period. As product quality choices may be perceived as longer, more strategic type of decisions, than inventory, in this section, we assume that the manufacturer determines the quality already in the first period, and the resulting sequence of events is presented in Figure S1.1.

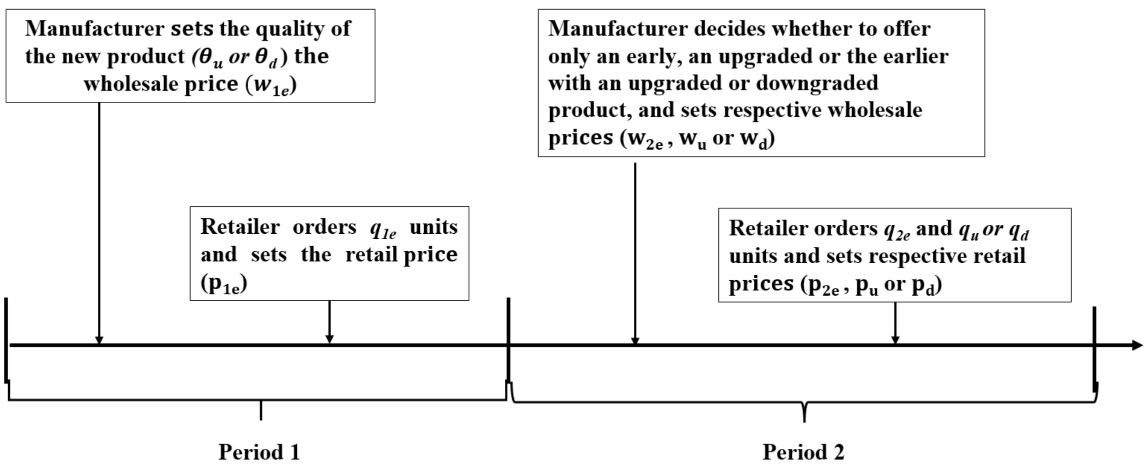

Figure S1.1: Sequence of events without strategic inventory and the manufacturer takes the quality decision in the first period.

The analysis in this section echoes that of the main manuscript. That is, we first analyze the case where the manufacturer offers both earlier and upgraded versions in the second period. And then in the following subsection, we derive the decision where the manufacturer offers only the upgraded version in the second period.

S1.1 Manufacturer offers both early and upgraded product in the second period:

Substituting $I = 0$ in Equation (9), we obtain the profit function in the second period for the retailer as:

$$\pi_{r2}(q_{2e}, q_u) = q_{2e}(p_{2e} - w_{2e}) + q_u(p_u - w_u) \tag{S1.1}$$

Because $\frac{\partial^2 \pi_{r2}}{\partial {q_{2e}}^2} = -2\theta < 0$ and $\frac{\partial^2 \pi_{r2}}{\partial {q_{2e}}^2} \cdot \frac{\partial^2 \pi_{r2}}{\partial {q_u}^2} - \left(\frac{\partial^2 \pi_{r2}}{\partial q_{2e} \partial q_u}\right)^2 = 4(\delta-1)\theta^2 > 0$, the retailer's profit function is concave in q_{2e} and q_u. Solving first order conditions for the retailer's profit function, $\left(\frac{\partial \pi_{r2}}{\partial q_{2e}} = 0 \text{ and } \frac{\partial \pi_{r2}}{\partial q_u} = 0\right)$ simultaneously, the selling quantity for the second period is obtained as follows:

$$q_{2e}(w_{2e}, w_u, \delta) = \frac{w_u - \delta w_{2e}}{2(\delta-1)\theta}, \quad q_u(w_{2e}, w_u, \delta) = \frac{(\delta-1)\theta - w_u + w_{2e}}{2(\delta-1)\theta} \tag{S1.2}$$

Note that the purchase quantity for each product is a decreasing function of their respective wholesale prices (w_{2e} or w_u). Therefore, if the manufacturer sets higher wholesale prices, then the retailer might not procure products in the second period, and those wholesale price thresholds can be obtained by solving $q_{2e} = 0$ and $q_u = 0$. On simplification, the upper bounds for wholesale prices are obtained as follows:

$$\ddot{w}_{2e}(w_u, \delta) = \frac{w_u}{\delta} \tag{S1.3}$$

$$\ddot{w}_u(w_{2e}, \delta) = w_{2e} + (\delta-1)\theta \tag{S1.4}$$

Therefore, the selling quantities for the retailer based on the wholesale prices offered by the manufacturer are as follows:

Lemma S1.1 *The selling quantity of the retailer in the second period will be*

$$q_{2e}(w_{2e}, w_u, \delta) = \begin{cases} \frac{w_u - \delta w_{2e}}{2(\delta-1)\theta} & \text{if } w_{2e} < \ddot{w}_{2e} \\ 0, & \text{otherwise} \end{cases}$$

$$q_u(w_{2e}, w_u, \delta) = \begin{cases} \frac{(\delta-1)\theta - w_u + w_{2e}}{2(\delta-1)\theta} & \text{if } w_u < \ddot{w}_u \\ 0, & \text{otherwise} \end{cases}$$

Using the optimal responses of the retailer obtained in Equation (S1.2), the second-period profit function for the manufacturer is obtained as:

$$\pi_{m2}(w_{2e}, w_u, \delta) = \frac{((\delta-1)\theta + w_{2e} - w_u)(w_u - \eta\delta^2\theta^2)}{2\theta(\delta-1)} + \frac{(w_u - w_{2e}\delta)(w_{2e} - \eta\theta^2)}{2\theta(\delta-1)} \tag{S1.5}$$

Profit function in Equation (S1.5) is concave because $\frac{\partial^2 \pi_{m2}}{\partial {w_{2e}}^2} = \frac{-\delta}{(\delta-1)\theta} < 0$ and $\frac{\partial^2 \pi_{m2}}{\partial {w_{2e}}^2} \cdot \frac{\partial^2 \pi_{m2}}{\partial {w_u}^2} - \left(\frac{\partial^2 \pi_{m2}}{\partial w_u w_{2e}}\right)^2 = \frac{1}{(\delta-1)\theta^2} > 0$, respectively. Now, solving the first order conditions with respect to w_{2e} and w_u, we obtain the following response:

$$\begin{aligned} w_{2e}(\delta, \theta) &= \frac{\theta(1+\eta\theta)}{2} \\ w_{2u}(\delta, \theta) &= \frac{\delta\theta(1+\delta\eta\theta)}{2} \end{aligned} \tag{S1.6}$$

Substituting the manufacturer's response from Equation (S1.6) in Equation (S1.2), we obtain the demand for the products in Period 2 as follows:

$$q_{2e}(\delta,\theta) = \frac{\delta\eta\theta}{4}, \quad q_u(\delta,\theta) = \frac{1-(1+\delta)\eta\theta}{4} \tag{S1.7}$$

By comparing the optimal wholesale price of the existing product with the boundary value (Equations (S1.3)), we obtain $\ddot{w}_{2e}(\theta) - w_{2e}(\theta) = \frac{(\delta-1)\eta\theta^2}{2} > 0$, and that of the upgraded product with the threshold (as given in Equations (S1.4)), we get $\ddot{w}_u - w_u = \frac{(1-(1+\delta)\eta\theta)(\delta-1)\theta}{2} > 0$ if $\delta < \frac{1-\eta\theta}{\eta\theta}$. Therefore, the manufacturer introduces the upgraded product along with the existing product if $\delta < \frac{1-\eta\theta}{\eta\theta}$. Using the responses obtained in Equations (S1.6) and (S1.2), the total profit function for the retailer in two periods is obtained as follows:

$$\pi_r(q_{1e}) = s_{1e}(\theta - s_{1e}\theta - w_{1e}) + \frac{\delta\theta(1-\eta\theta(2\delta+(1-\delta-\delta^2)\eta\theta))}{16} \tag{S1.8}$$

Because, $\frac{\partial^2\pi_r}{\partial {q_{1e}}^2} = -2\theta < 0$, the profit function for the retailer is concave in q_{1e}. Now solving the first-order condition for the profit function in Equation (S1.8), the response for the retailer is obtained as:

$$q_{1e}(w_{1e}) = \frac{\theta - w_{1e}}{2\theta} \tag{S1.9}$$

Finally, using Equations (S1.9) and (S1.6) in Equation (S1.5), the total profit for the manufacturer in two periods is obtained as:

$$\pi_m(w_{1e}) = \frac{(\theta - w_{1e})(w_{1e} - \eta\theta^2)}{2\theta} + \frac{\delta\theta(1-\eta\theta(2\delta+(1-\delta-\delta^2)\eta\theta))}{8} \tag{S1.10}$$

Because $\frac{\partial^2\pi_m}{\partial w_{1e}^2} = -\frac{1}{\theta} < 0$ and $\frac{\partial^2\pi_m}{\partial w_{1e}^2}\cdot\frac{\partial^2\pi_m}{\partial\delta^2} - \left(\frac{\partial^2\pi_m}{\partial\delta\partial w_{1e}}\right)^2 = \frac{\eta\theta(2-\eta(\theta+3\delta\theta))}{4}$, therefore, the manufacturer's profit function is concave if $\delta < \frac{2-\eta\theta}{3\eta\theta}$. Solving the first order condition, we obtain the wholesale price in the first period as

$$\begin{aligned} \{w_{1e},\delta\} &= \left\{\frac{\theta(1+\eta\theta)}{2}, \frac{1+\eta\theta}{3\eta\theta}\right\} \\ \{w_{1e},\delta\} &= \left\{\frac{\theta(1+\eta\theta)}{2}, \frac{1-\eta\theta}{\eta\theta}\right\} \end{aligned} \tag{S1.11}$$

Therefore, the manufacturer introduces the upgraded product along with the existing product if $\delta < \frac{1-\eta\theta}{\eta\theta}$. It implies that the second solution is not feasible. Furthermore, we verified that $(2-\eta(\theta+3\delta\theta))|_{\delta=\frac{1+\eta\theta}{3\eta\theta}} = 1-2\eta\theta > 0$ if $\theta < \frac{1}{2\eta}$. Substituting the optimal value obtained in Equation (S1.11), we get the final responses of the members, which is identical to the response presented in Table 3 under Scenario EUN. Therefore, the optimal solutions remain independent from the decision sequence when the manufacturer offers an upgraded product with the existing product.

S1.2 Manufacturer offers only upgraded product in the second period:

In this strategy, the manufacturer offers an existing version in the first period and only an upgraded version in the second period. Therefore, the profit function of the retailer in the second period is obtained as follows:

$$\pi_{r2} = q_u(p_u - w_u) \tag{S1.12}$$

The profit function in Equation (S1.12) is concave because $\frac{d^2\pi_{r2}}{dq_u{}^2} = -2\delta\theta < 0$ and we obtain the selling quantity for the upgraded product by solving the first-order condition as follows:

$$q_u(w_u, \delta) = \frac{\delta\theta - w_u}{2\delta\theta} \tag{S1.13}$$

Once again, the order quantity in Equation (S1.13) decreases with the wholesale price. The retailer cannot buy any product in the second period if the manufacturer sets a wholesale price above the threshold $w_u = \hat{w}_u(\delta) = \delta\theta$. Using the response given in Equation (S1.13), the profit function for the manufacturer becomes

$$\pi_{m2}(w_u, \delta) = \frac{(\delta\theta - w_u)\,(w_u - \eta\theta^2\delta^2)}{2\delta\theta} \tag{S1.14}$$

The profit function in Equation (S1.14) is concave because $\frac{d^2\pi_{m2}}{dw_u{}^2} = -\frac{1}{\delta\theta} < 0$. Solving first-order conditions, we get the following response:

$$w_u(\theta) = \frac{\delta\theta(1 + \delta\eta\theta)}{2} \tag{S1.15}$$

Therefore, the demand of the upgraded product is $q_u = \frac{(1-\delta\eta\theta)}{4} > 0$. Substituting the response obtained in Equations (S1.13) and (S1.15) in Equation (S1.12), the total profit for the retailer is obtained as:

$$\pi_r(q_{1e}) = s_{1e}(\theta - s_{1e}\theta - w_{1e}) + \frac{\delta\theta(1 - \delta\eta\theta)^2}{16} \tag{S1.16}$$

The profit function for the retailer in Equation (S1.16) is concave, as $\frac{\partial^2\pi_r}{\partial q_{1e}{}^2} = -2\theta < 0$. By solving the first-order condition, the response for the retailer is obtained as follows:

$$q_{1e}(w_{1e}) = \frac{\theta - w_{1e}}{2\theta} \tag{S1.17}$$

Substituting responses obtained from Equations (S1.17) and (S1.15) in Equation (S1.14), the total profit for the manufacturer in the first period is obtained as:

$$\pi_m(w_{1e}, \delta) = \frac{(w_{1e} - \eta\theta^2)(\theta - w_{1e})}{2\theta} + \frac{\delta\theta(1 - \delta\eta\theta)^2}{8} \tag{S1.18}$$

Profit function for the manufacturer is concave if $\delta < \frac{2}{3\eta\theta}$ because $\frac{\partial^2 \pi_m}{\partial w_{1e}^2} = -\frac{1}{\theta} < 0$ and $\frac{\partial^2 \pi_m}{\partial w_{1e}^2} \times \frac{\partial^2 \pi_m}{\partial \delta^2} - \left(\frac{\partial^2 \pi_m}{\partial w_{1e} \partial \delta}\right)^2 = \frac{\eta\theta(2-3\delta\eta\theta)}{4} > 0$. Solving the first order conditions, the manufacturer's response is obtained as follows:

$$
\begin{aligned}
\{w_{1e}(\theta), \delta(\theta)\} &\equiv \left\{\frac{\theta(1+\eta\theta)}{2}, \frac{1}{3\eta\theta}\right\} \\
\{w_{1e}(\theta), \delta(\theta)\} &\equiv \left\{\frac{\theta(1+\eta\theta)}{2}, \frac{1}{\eta\theta}\right\}
\end{aligned}
\tag{S1.19}
$$

One can verify that if $\delta = \frac{1}{\eta\theta}$, the concavity condition is violated. Therefore, the decision remains the same if the manufacturer determines the quality of the upgraded product in the first period.