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Increasing Quality Sequence: When Is It an Optimal Product Introduction Strategy?

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In this paper, we analyze the optimal introduction timing of a seller's products targeted at segments that differ in their willingness to pay for quality. Past studies suggest that an introduction sequence of a high-quality product followed by a lower-quality version of the product may mitigate the cannibalization effects of the low-quality product on profits from the high-quality product. We show that if customers who value quality more possess an outside option such as a substitute product, as may be the case with replacement buyers, a seller may find it optimal to follow a low-quality product with a higher-quality one, the latter being targeted at replacement buyers. Furthermore, the ability of the seller to commit to future qualities accentuates the sequential increase in quality in the presence of such buyers. Thus, we show that conditions other than uncertainty or technological improvements occurring over time may justify a seller adopting a strategy of sequentially increasing quality.

Keywords: new product introduction; game theory; marketing strategy; market segmentation; product differentiation; durable products; pricing

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1. Introduction

How should a seller introduce products that vary in their quality or functionality? Should the seller introduce these products simultaneously or sequentially, and if the latter, in what sequence? This question has been posed and answered before, specifically in a seminal paper by Moorthy and Png (1992), who consider a seller facing two customer segments that differ in their marginal valuation for quality. They find that the seller would follow a down-market stretch strategy (Kotler and Keller 2006) of offering the lower-quality product after the higher-quality product rather than simultaneously, if customers were relatively impatient. Such a sequential introduction mitigates the cannibalization effect of a lower-quality product on the sales of a higher-quality product.

In this paper, we extend the study by Moorthy and Png (1992) to a situation where the customer segment with the higher marginal valuation of quality has a lower overall value of a new product, because it has a valuable outside option. Such a scenario may potentially arise if this customer segment consists of replacement buyers who own a substitute product but nevertheless have a higher marginal valuation for quality because of their prior experience with the product category. For simplicity, we refer to this segment in our model as *replacement buyers*, and a second segment with a lower marginal valuation of quality and no outside option is

referred to as *first-time buyers*. Our analytical model consists of a monopoly seller deciding on the timing of introduction, qualities, and prices of products in his product line to serve these two customer segments.

Our main finding is that when the number of replacement buyers and the value of their outside options are sufficiently high, the seller follows a strategy of up-market stretch by introducing a higher-quality product after the lower-quality product, targeting the former product at replacement buyers. This finding is in contrast to Moorthy and Png (1992), where the top-of-the-line product is never delayed and customer segments with the highest marginal valuation of quality are always served first under a sequential introduction strategy. The key difference is that the cannibalizing product is the lower-quality product in Moorthy and Png, whereas it is the higher-quality product in our model, with this product targeting buyers with the outside option. As these buyers demand a lower price, a delay in serving these buyers mitigates cannibalization of sales to first-time buyers.

In contrast to our paper, the literature on the strategic rationale for delayed introduction of higher-end products depends principally on the presence of some form of uncertainty. Biyalogorsky and Koenigsberg (2010) show that when a firm faces a high level of demand uncertainty, it may introduce a lower-quality

product initially and follow it up later with a higher-quality product if the demand turns out to be high. Padmanabhan et al. (1997) show that in the presence of network externalities, a firm may offer sequentially increasing quality when signaling the extent of its installed base to uncertain customers.¹

Our findings may explain the delayed introduction of the high-end product in some instances. For example, Honda entered the U.S. market with an entry-level motorcycle targeting the new motorcycle user and subsequently introduced higher-end products appealing to replacement buyers. Similarly, Southwest Airlines, which entered the market as a no-frills airline appealing to passengers who travel by road, has recently begun offering business class amenities, appealing to regular flyers who faced high switching costs from other airlines because of their frequent flyer programs. In 2007, Mercedes-Benz introduced a newer model of its C-class car, the C350, several months before launching a newer model of its higher-performance C63 AMG car (Tan 2007). Mercedes-Benz also followed an increasing quality sequence with previous major redesigns of C-class and AMG cars, suggesting further that the sequencing choice is strategic. Furthermore, anecdotal evidence suggests that the delayed high-quality Mercedes-Benz C63 AMG in the example appeals to replacement buyers, consistent with our model (Lassa 2011). Similarly, BMW and Audi routinely delay their high-performance M versions and S models, respectively.

2. Analytical Model

We consider a seller designing and pricing a line of infinite-lived durable products and formulating an introduction strategy to serve a market consisting of two customer segments, a first-time buyer segment, segment f , and a replacement buyer segment, segment r , of sizes n_f and n_r , respectively. We define $\nu \equiv n_r/n_f$. The product's design can be differentiated on an attribute on which all customer segments have the same preference ordering but have different valuations. An example of such an attribute, which we refer to as "quality" in this paper, is engine power or gas mileage of an automobile (see Moorthy and Png 1992). Segment f values a unit of product with quality q at $\theta_f q$, whereas a customer belonging to segment r has a marginal valuation for quality of θ_r , with $\theta_r > \theta_f > 0$. We can interpret θ_f and θ_r as the discounted present value of the services derived from a unit of quality of the durable product.

We also assume that a customer in segment r has a total valuation of a unit of the product reduced by R ($R > 0$). Thus, segment r values a product of quality q

at $\theta_r q - R$. We interpret the decrease in valuation by R to signify that segment r possesses a highly valued outside option in the form of a previously purchased substitute product of older technology (thus our nomenclature for segment r as replacement buyers).² Under this interpretation, R would represent the utility that segment r obtains from this older product less any salvage value that can be obtained from disposing this older product—say, by selling it in a used product market or by trading it in.³ Note that our assumption that $R > 0$ implies that segment r values the old product more than the price it can get for it in the used product market. In contrast to segment r , we can consider segment f either to be made up of first-time buyers or to be made up of buyers who possess previously purchased substitute products that they value less than their disposal values.⁴

The assumption that the marginal valuation of quality for replacement buyers is higher than that of first-time buyers is consistent with Wathieu (2004), who suggests that sensitization and habituation (which have a neurobiological and psychological basis) to a product's benefits cause consumers to value a product more after experience. Furthermore, anecdotal evidence also supports this assumption. For example, the marketing manager of Samsung microwave ovens had the following comment: "We're continually seeing the replacement buyer shopping and trading up to larger ovens. . . . When they do that, they want larger cavity size, more features, greater flexibility, ease of use and white on white" (Pfaff 1993, p. 90).

Our assumptions about segment r are consistent with the equilibrium results for durable goods markets obtained by Hendel and Lizzeri (1999), who show that in equilibrium, there is a segment (similar to our

² Another interpretation is that segment r may be in the market for a second unit of the product (such as a second car) and hence is willing to pay less than segment f by a magnitude of R .

³ More formally, let U_o^r represent segment r 's valuation of its currently owned substitute product, and let p_u be the market price of this product in the used product market. Furthermore, let U_n^r denote segment r 's valuation of a new product when this segment owns no substitute product, and let p_n be the price of the new product. Suppose further that a consumer from segment r values the old product at zero if he purchases the new product. Then, this consumer's optimal strategy when purchasing the new product is to sell the old product in the used product market. Under these assumptions, segment r 's surplus when purchasing the new product equals $(U_n^r - p_n) + p_u$. On the other hand, its surplus from staying with the old product is U_o^r . Equating the two surpluses, we obtain the maximum price that segment r would be willing to pay for the new product to be $p_n = U_n^r - (U_o^r - p_u)$. This expression for segment r 's valuation for a new product is similar to that assumed in our model above if we set $U_n^r = \theta_r q$ and $R = U_o^r - p_u$. Note that R can also reflect transaction costs in selling a used product.

⁴ Under this assumption, we can similarly show that the maximum price that segment f would pay for the new product would equal its valuation, $\theta_f q$, of this product.

¹ In related literature, Levinthal and Purohit (1989) and Bayus (1992) study the introduction of new higher-quality products resulting from exogenous technological innovations.

r segment) that values its existing product more than the used product price because of adverse selection (see Akerlof 1970). Although Hendel and Lizzeri (1999) model the used product market, they assume the supply of new products to be exogenous. In contrast, we implicitly assume an exogenous used product market (their influence is captured through the R parameter) and focus on new product introduction strategies.

Because R represents the decrease in utility of the new product to segment r as a result of current ownership of a high-quality substitute product, we refer to R as the “possession effect” in this paper. Gordon (2009) provides empirical evidence of the possession effect among owners of existing products in the PC market. Consistent with the previous literature (see Moorthy and Png 1992), we assume that for each product in his product line, the seller incurs a constant marginal cost that increases with the product’s quality, q , and is given by cq^2 , where $c > 0$. We assume that introductory fixed costs for offering a new product are sufficiently small such that they do not constrain the seller from offering the widest possible product line that would maximize his profit before subtracting fixed costs.

In our model, the seller has the opportunity to introduce one or more products at the beginning of a succession of periods, starting with period 1. Each period determines a potential product introduction date that may be customary for an industry. For example, new models of automobiles in the United States are typically introduced in the fall season. We assume that the seller’s discount factor for future profits is δ_s per period, $0 \leq \delta_s < 1$. The seller decides which segments to serve and when, as well as the quality and price of the product to offer to each such segment. We use q_f and q_r to denote the qualities and p_f and p_r to denote the prices that the seller intends for the customers of segments f and r , respectively.

We assume that the seller cannot identify customers from different segments so that perfect product and price discrimination is not possible, implying that the seller has to rely on consumer self-selection.⁵ Furthermore, we assume in our initial analysis in §3 that the seller cannot commit to product qualities or prices that will be offered in the future. This assumption has the appealing property that the seller’s actions in every period maximize his profits going forward. Subsequently, in §4, we consider the case where the seller can commit to the qualities of future product offerings in advance. For simplicity, we also assume that segment r ’s possession effect, R , remains unchanged over the two periods under consideration. A stationary value for R would be approximately the case if the

time elapsed between the periods is short. However, this assumption is not critical to our results.⁶

Customers purchase at most one unit of the product and choose the product in the seller’s product line that would offer the highest surplus (the self-selection requirement), provided this surplus is nonnegative (the participation constraint), where surplus is the product’s valuation less its price. We assume that customers exit the market after purchase. Customers may delay their purchases to obtain a higher surplus from a future product anticipated from the seller, discounting any future surplus at the rate of δ_c per period ($0 \leq \delta_c < 1$). We solve for a pure-strategy rational expectations equilibrium in which customers’ expectations are rational given the seller’s sequential strategy and the seller’s sequential strategy is optimal given customers’ expectations (cf. Moorthy and Png 1992, Tirole 1988, Waldman 1996). In solving for equilibrium, we need to consider the deviation of one player at a time (cf. Gul et al. 1986). Thus, for customers, equilibrium requires us to consider the deviation of one customer from one segment at a time. As is common in such models, we assume that each segment has many customers (n_f and n_r are large). Thus, an individual customer has an infinitesimal effect on the seller’s profit, implying that the seller would not modify his strategy because of deviation by an individual customer (see Gul et al. 1986, Villas-Boas 2004).

If the seller serves each segment in isolation, there would be no cannibalization concerns, and each segment would be offered its profit-maximizing quality (also called “efficient” quality) and charged the “full price” that extracts its entire surplus. We use the shorthand notation q_f^e and q_r^e to refer to the efficient qualities for segments f and r , respectively, with the corresponding “full prices” being referred to as p_f^e and p_r^e , respectively. It can be shown that $q_f^e = \theta_f/(2c)$, $q_r^e = \theta_r/(2c)$, $p_f^e = \theta_f^2/(2c)$, and $p_r^e = \theta_r^2/(2c) - R$. Our assumptions on valuations and costs ensure that the seller can profitably offer a product to segment f when serving it in isolation. For segment r , we assume that R is not too large, as shown below, so that the seller could profitably serve this segment in isolation.

$$R \leq \theta_r^2/(4c). \quad (1)$$

3. Analysis with No Seller Commitment

3.1. Alternative Equilibrium Sequences

In this section, we assume that the seller cannot commit to a product line strategy in advance. Given this

⁵ Because segment f may also possess an existing product, albeit a low-quality one whose quality cannot be publicly observed, it would be difficult to distinguish it from segment r .

⁶ If R decreases with time because of depreciation of segment r ’s existing product, the r segment would become more receptive to buying later, further facilitating a delayed introduction of higher quality.

assumption, the seller would find it profitable to serve the remaining segment after serving one segment (cf. Moorthy and Png 1992). Our model assumptions and Equation (1) ensure that serving residual segments is profitable for the seller. Thus, in a pure-strategy rational expectations equilibrium, we could have both segments buying simultaneously or sequentially giving rise to one of the following possibilities: $\{f, r\}$, $\{r, f\}$, or $\{f \& r\}$. This notation for the equilibria lists the order in which the segments are served in each equilibrium, with segments served in the same period and in distinct periods separated by an ampersand (&) and a comma, respectively. With two segments and $\delta_s < 1$, we need to consider at most two periods if the seller serves the two segments sequentially.⁷ Thus, the equilibrium sequence $\{f, r\}$ indicates that segment f is served in the first period while segment r is served in the second period, whereas $\{r, f\}$ denotes an equilibrium with the reverse sequence. In the sequence $\{f \& r\}$, the seller serves segments f and r simultaneously in the first period. Omitted proofs are available directly from the authors.

3.2. Benchmark Analysis: $\{f \& r\}$

We begin with an analysis of the benchmark equilibrium, $\{f \& r\}$, in which the seller serves both segments simultaneously and faces the following optimization problem:

$$\text{Maximize}_{q_r, p_r, q_f, p_f} \pi_s = n_f(p_f - cq_f^2) + n_r(p_r - cq_r^2)$$

$$\text{subject to } \theta_r q_r - R - p_r \geq 0, \quad (2)$$

$$\theta_f q_f - p_f \geq 0, \quad (3)$$

$$\theta_f q_f - p_f \geq \theta_r q_r - p_r, \quad (4)$$

$$\theta_r q_r - R - p_r \geq \theta_r q_f - R - p_f. \quad (5)$$

In the above problem, inequalities (2) and (3) represent the participation constraints for segments r and f , respectively, and inequalities (4) and (5) are the self-selection constraints that require each served segment to prefer the product quality intended for it. In this equilibrium, a customer in either segment does not expect to gain by delaying purchase, because with the market clearing at the end of the period (with the exception of the deviating customer), the seller would optimally extract all surplus from the deviating customer. Thus, the expected surplus from not purchasing is zero, as represented by inequalities (2) and (3).

In the $\{f \& r\}$ equilibrium solution to the above problem, when R is low, the seller reduces q_f below its

efficient level of q_f^e while offering segment r its efficient quality of q_r^e . This strategy of reducing the quality to the segment with the lower marginal valuation of quality, as noted in many papers (see Moorthy 1984, Mussa and Rosen 1978), enables the seller to optimally dissuade segment r from choosing q_f (satisfying constraint (5)).⁸ However, when R is high ($R \geq \theta_r(\theta_r - \theta_f)/2c$), and with q_r at its efficient level, the seller's full price for q_r (that captures all customer surplus) is so low that segment f would prefer q_r to q_f . To prevent segment f from switching to q_r , the seller increases q_r to make it less attractive to segment f , as this segment values increases in q_r less than segment r . In doing so, the seller sacrifices some profit from segment r in order to extract more profit from segment f . Note that this upward distortion of the higher-quality product when R is high is different from the downward distortion in the lower-quality product when R is low. The possibility of a seller thus distorting the higher-quality product in his product line was first discussed by Srinagesh and Bradburd (1989). They generalize Mussa and Rosen (1978) to show that although the segment with the higher marginal valuation of quality would always get the higher-quality product, the cannibalizing product, whose quality is distorted, is always the product that is targeted to buyers with lower total valuation. Thus, no matter the value of R , segment r , with its higher marginal valuation for quality, is always offered the higher quality. However, when R is high, segment r has a lower total valuation for quality in comparison to segment f , and thus the higher quality, q_r , is distorted upward to dissuade cannibalization of q_f . On the other hand, when R is low, segment f has the lower total valuation and the lower quality, q_f , is distorted downward to mitigate cannibalization of q_r , similar to Mussa and Rosen.

In sum, the main conclusion from the benchmark case is that the cannibalizing product changes from q_f to q_r as R increases. Although Srinagesh and Bradburd (1989) discuss the theoretical possibility of q_r being the cannibalizing product, our analysis shows that we may obtain such a scenario when there are replacement buyers. We now proceed to discuss the equilibrium sequences $\{f, r\}$ and $\{r, f\}$.

3.3. Main Result on Sequentially Increasing Quality

To identify the conditions for sequentially increasing quality, we analyze the equilibrium sequences, $\{f, r\}$ and $\{r, f\}$. We briefly discuss here the analysis of the $\{f, r\}$ equilibrium but omit discussion of the analogous $\{r, f\}$ equilibrium. We use backward induction to solve for the rational expectations equilibrium with a

⁷ If there is a pure-strategy rational expectations equilibrium that requires more than two periods for all segments to be served, the seller can do strictly better by moving up the timing of his product introductions to the first two periods, because $\delta_s < 1$.

⁸ Some other papers that consider the general issue of separating customers through self-selection include Villas-Boas (1998), Subramanian et al. (2014), and Xiong and Chen (2014).

sequence of $\{f, r\}$. Thus, we first consider the seller's optimal product line and prices in the final period (period 2) to serve segment r that remains in the market. In particular, in period 2, the seller chooses q_r and p_r to maximize his profits $\pi_{s2} = n_r(p_r - cq_r^2)$ subject to the participation constraint (2) presented earlier. After solving for the seller's optimal qualities and prices, q_r^* and p_r^* targeted to segment r , we solve the seller's first-period optimization problem specified below:

$$\text{Maximize}_{q_f, p_f} \pi_s = n_f(p_f - cq_f^2) + \delta_s \pi_{s2}$$

$$\text{subject to } \theta_f q_f - p_f \geq 0, \quad (6)$$

$$(\theta_f q_f - p_f) \geq \delta_c (\theta_f q_r^* - p_r^*), \quad (7)$$

$$\delta_c (\theta_r q_r^* - R - p_r^*) \geq (\theta_r q_f - R - p_f). \quad (8)$$

The participation constraint (6) for segment f is identical to constraint (3) in the benchmark case. However, the self-selection constraints account for the timing differences of the product offers. In any rational expectations equilibrium with sequence $\{f, r\}$, segment f should prefer q_f to the product that he expects the seller to offer in the second period, as formalized by constraint (7). Note that the constraint assumes that customers correctly anticipate the seller's offer in the second period, consistent with a rational expectations equilibrium. If constraints (6) and (7) are satisfied, no consumer in segment f can gain by deviating from purchasing q_f in period 1 with a view to delaying purchase.⁹ Similarly, constraint (8) requires that segment r prefers the expected q_r in period 2 to purchasing q_f in period 1.

We solve similarly for the $\{r, f\}$ equilibrium to set up Proposition 1, which presents the conditions under which the seller's profits are highest in the equilibrium with sequentially increasing quality—namely, the $\{f, r\}$ equilibrium. Note that the pure-strategy rational expectations equilibrium identified for each of the sequences $\{f, r\}$, $\{r, f\}$, and $\{f \& r\}$, is unique. Without loss of generality, Proposition 1 presents the results (with $\nu \equiv n_r/n_f$) when δ_s is infinitesimally smaller than 1 ($\delta_s \rightarrow 1$) because of the simpler resulting expressions. Later we briefly discuss the results for general δ_s .

PROPOSITION 1. *When $\delta_s \rightarrow 1$, the seller's profit is highest when offering sequentially increasing quality in the $\{f, r\}$ equilibrium with $q_f = q_f^e$, $q_r = q_r^e$, $p_f = p_f^e - \delta_c [R - \theta_r(\theta_r - \theta_f)/(2c)]$, and $p_r = p_r^e$ if*

$$(a) \delta_c \leq \frac{1}{2} \text{ and}$$

$$R \geq \theta_r(\theta_r - \theta_f)/(2c) + \delta_c(\theta_r - \theta_f)^2/(c\nu);$$

$$(b) \delta_c \geq \frac{1}{2} \text{ and}$$

$$R \geq \theta_r(\theta_r - \theta_f)/(2c) + (\theta_r - \theta_f)^2/(4c\nu(1 - \delta_c)).$$

Proposition 1 shows that sequentially increasing quality offers from the seller in an $\{f, r\}$ equilibrium yields the highest profit when R is sufficiently high. In this equilibrium, the seller offers both segments their efficient qualities with segment r being served later. Given the lower marginal valuation of quality for segment f , we obtain $q_r > q_f$.¹⁰ However, with R being high, the seller is concerned about segment f 's incentive to delay purchase until period 2 in order to choose q_r . Therefore, the seller reduces p_f to offer a positive surplus to segment f , thereby preventing cannibalization of q_f by q_r . Note that for the same high values of R , under the $\{f \& r\}$ equilibrium q_r would be distorted upward above its efficient level to extract more surplus from the f segment while preventing cannibalization of q_r by q_f .

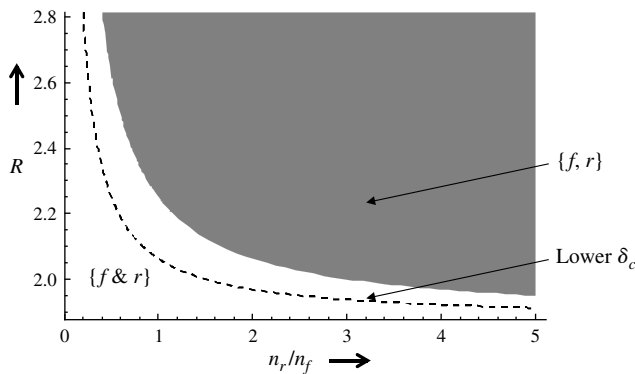
It may be worth noting that for the conditions in Proposition 1, all three equilibria $\{f, r\}$, $\{r, f\}$, and $\{f \& r\}$ can exist but that the seller's profit is highest in the $\{f, r\}$ equilibrium. In spite of the multiple equilibria, a seller, who is incapable of commitment, can influence the equilibrium played and customer expectations. For example, by offering in period 1 the product q_f at a price p_f , as given in Proposition 1, the seller induces expectations and customer behavior consistent with an $\{f, r\}$ equilibrium.

In Figure 1, the shaded region represents the area where the $\{f, r\}$ equilibrium yields the highest profit, consistent with Proposition 1.¹¹ Note that the figure only represents the case when R is sufficiently high ($R \geq \theta_r(\theta_r - \theta_f)/2c$). The figure shows that for such R , the $\{f, r\}$ equilibrium is the most profitable one except when R and n_r/n_f are relatively low. These latter conditions favor the $\{f \& r\}$ equilibrium for the seller because the strategy of distorting q_r upward in the $\{f \& r\}$ equilibrium is not very costly for these parameters. Recall that in an $\{f \& r\}$ equilibrium at high R the seller sacrifices profits from the r segment through the quality distortion to extract more surplus from the f segment. However, if n_r/n_f is higher, i.e., a relatively larger r segment, the lost profit from this segment becomes higher, rendering the $\{f, r\}$ equilibrium more profitable. Similarly, if R is higher, the $\{f \& r\}$ equilibrium becomes less profitable in comparison to $\{f, r\}$, because the former equilibrium makes q_r available at a low price in an earlier period, exacerbating cannibalization of q_f .

¹⁰ Note that Proposition 1 implies that offering segment f 's product to segment r later, albeit at a lower price, is suboptimal. However, such a strategy can be optimal if there are significant product development and introduction costs.

¹¹ Figure 1 is drawn using the following parameters: $\theta_r = 1.5$, $\theta_f = 1$, $\delta_c = 0.3$, and $c = 0.2$.

⁹ Recall that deviation by an individual consumer does not cause the seller to change his strategy in a later period.

Figure 1 Model with No Commitment: Optimality for Strategy $\{f, r\}$ when $R \geq (\theta_r(\theta_r - \theta_f))/(2c)$ 

Finally, a lower δ_c makes time a stronger differentiating factor, thus enlarging the space for which the $\{f, r\}$ equilibrium is the most profitable, as indicated by the dashed line in Figure 1.

An interesting point in Figure 1 is that the $\{f, r\}$ equilibrium does not have a boundary with the $\{r, f\}$ equilibrium. The rationale is that the $\{r, f\}$ equilibrium can be best for the seller only at very low R , when q_f rather than q_r is the cannibalization threat. In other results for the $\{f, r\}$ equilibrium, $q_r > q_f$, consistent with our above discussion, but the comparison between p_f and p_r is ambiguous. Interestingly, profit margins per unit are lowest on the highest-quality product, q_r , consistent with the relatively high levels of R required for the $\{f, r\}$ equilibrium to be most profitable. This result may also be consistent with a comment by an industry expert that carmakers do not make a lot of profit from high-end models such as the Mercedes AMG (Barnes 2007). The lower profit margins from replacement buyers, who buy later under the $\{f, r\}$ strategy, may also be consistent with the typical decline in margins as the product life cycle matures. Comparative statics analysis of the $\{f, r\}$ equilibrium also shows that the seller's prices and profits decrease with R and δ_c , whereas the qualities offered are unchanged with R and δ_c .

As an aside, it may be interesting to note that the conditions favoring the simultaneous introduction equilibrium, $\{f \& r\}$, in Figure 1 may be such that the seller incurs a loss on the excessively high quality offered to the r segment. For example, assume $\theta_r = 1.5$, $\theta_f = 1$, $\delta_c = 0.95$, $n_f = 1$, $n_r = 2$, $R = 2.785$, $c = 0.2$, and $\delta_s \rightarrow 1$. In this case, the seller's profit is highest in an $\{f \& r\}$ equilibrium with $q_r = 4.375$ and $p_r = 3.778$. However, the seller's profit from the r segment in the $\{f \& r\}$ equilibrium is negative at -0.101 . In the alternative $\{f, r\}$ equilibrium, the seller would offer the r segment its efficient quality of 3.75, deriving a profit of 0.055 from this segment. Nevertheless, the seller prefers to serve both segments simultaneously even though he incurs a loss from the r segment. The seller's profit in the $\{f \& r\}$ equilibrium is 0.551, higher than

the profit of 0.44 in the $\{f, r\}$ equilibrium. Intuitively, serving the r segment early even at a loss reduces cannibalization more in this case than deferring to a future period when the seller will optimally not choose to distort the quality upward. However, if n_r becomes sufficiently high, say, $n_r = 6.9$, the lost profit from the r segment becomes so high in an $\{f \& r\}$ equilibrium that the seller is better off in the $\{f, r\}$ equilibrium (see Figure 1).

In Proposition 1, we assume that $\delta_s \rightarrow 1$ for simplicity. Although our above example has $\delta_c < \delta_s$, neither of these assumptions are required for a strategy of sequentially increasing quality. Thus, we can show that the seller's profit is highest in the $\{f, r\}$ equilibrium for the following numerical example with $\delta_c = \delta_s$: $\theta_r = 1.5$, $\theta_f = 1$, $\delta_c = 0.9$, $\delta_s = 0.9$, $n_f = 1$, $n_r = 4.01$, $R = 2.785$, and $c = 0.2$. In contrast, Moorthy and Png (1992) find that the seller introduces products sequentially only when $\delta_c < \delta_s$.

4. Seller Capable of Commitment to Future Quality

Previously, we analyzed our model under the assumption that the seller cannot commit to product qualities in advance. In this section, we relax this assumption and study how the results change if the seller can credibly commit to the timing of product introductions and the products' qualities. The difference between the solution here and the previous analysis without commitment is that the qualities of the seller's future products are determined in advance at the beginning of period 1. We assume, however, that prices are not committed to in advance and are announced at the time of the product's introduction. In addition to the strategies, $\{f \& r\}$, $\{f, r\}$, and $\{r, f\}$, the seller can now commit to not serve a customer segment. Thus, we need to consider two additional strategies, $\{f\}$ and $\{r\}$, that have the seller serving only segment f or r , respectively, in period 1. Without loss of generality, we assume that the sequential strategies $\{f, r\}$ and $\{r, f\}$ involve introductions in periods 1 and 2. Our interest once again centers on a seller strategy that results in sequentially increasing quality. Out of the alternative strategies discussed above, the $\{f, r\}$ strategy is once again the only one that results in sequentially increasing quality. Proposition 2 presents the conditions under which the seller prefers $\{f, r\}$ to the alternative strategies of $\{f \& r\}$, $\{r, f\}$, $\{f\}$, and $\{r\}$. As in the case of Proposition 1, we present the results when δ_s is infinitesimally smaller than 1 ($\delta_s \rightarrow 1$) without loss of generality, for simplicity.

PROPOSITION 2. When $\delta_s \rightarrow 1$, and $\theta_r(\theta_r - \theta_f)/(2c) + \delta_c(\theta_r - \theta_f)^2/(2cv) \leq R \leq (\nu\theta_r + \delta_c(\theta_r - \theta_f))^2/(4cv(\delta_c + \nu))$, the seller's optimal strategy is $\{f, r\}$ with $q_f = q_f^e$, $q_r = q_r^e + \delta_c(\theta_r - \theta_f)/(2cv)$, $p_f = p_f^e - \delta_c[R - \theta_r(\theta_r - \theta_f)/(2c)] + \delta_c^2(\theta_r - \theta_f)^2/(2cv)$, and $p_r = p_r^e + \delta_c\theta_r(\theta_r - \theta_f)/(2cv)$.

Similar to Proposition 1, Proposition 2 shows that the seller prefers the $\{f, r\}$ strategy that results in sequentially increasing quality only when R is high. The intuition for this result is similar in that segment f becomes the cannibalizing segment when R is high. Consequently, the seller delays q_r to reduce cannibalization. However, in contrast to the no-commitment case, the seller also distorts q_r above q_r^e for segment r , thus realizing another means to reduce cannibalization when delaying q_r . Furthermore, comparison of q_r in Proposition 2 and in the $\{f \& r\}$ equilibrium shows that the seller can reduce the distortion above q_r^e by delaying q_r . Thus, under commitment, the seller prefers an $\{f, r\}$ strategy rather than an $\{f \& r\}$ strategy at lower levels of R in comparison to Proposition 1. This conclusion is supported by contrasting Figures 1 and 2, which shows the regions of optimality of the $\{f, r\}$ strategy under commitment for the same parameters as Figure 1 and for high R ($R \geq \theta_r(\theta_r - \theta_f)/(2c)$). Furthermore, Figure 2 shows that when R is sufficiently high, the seller commits to not serving segment r at all in order to reduce cannibalization of segment f . In this context, we may note that in the commitment case, the seller would always make a profit from segment r whenever he offers the product because of the ability to commit to not offering a product that reduces total profits. In contrast, recall that in the no-commitment case, the seller may tolerate a loss from segment r in the $\{f \& r\}$ equilibrium to avoid the higher cannibalization from offering q_r^e to segment r in an $\{f, r\}$ equilibrium.

Figure 2 also shows that the seller adopts an $\{f, r\}$ strategy only when n_r/n_f is sufficiently high, signifying a more valuable r segment that the seller would like to serve with a smaller profit-reducing quality distortion. As in the no-commitment case, a lower δ_c expands the region of optimality of the $\{f, r\}$ strategy (not shown in Figure 2). Overall, given that the commitment capability allows the seller to commit to an upwardly distorted future quality for segment r (and thus overcome his incentive to offer this segment its efficient quality at a future date), it is not surprising that the seller's

profits can be shown to be higher under commitment. Furthermore, the increase in the quality of the product offerings over time is higher for a sequential introduction strategy under commitment. As in the case of Proposition 1, the result in Proposition 2 does not depend on $\delta_s \rightarrow 1$, although this assumption simplifies the analysis. For example, using the profit expressions from the proof of Proposition 2, we can show that the seller adopts the strategy $\{f, r\}$ for the following parameters: $\theta_r = 1.5$, $\theta_f = 1$, $\delta_c = 0.9$, $\delta_s = 0.9$, $n_f = 1$, $n_r = 1.31$, $R = 1.985$, and $c = 0.2$.

5. Conclusion and Managerial Implications

In this paper, we show that a seller may strategically delay offering the highest-quality product in his product line even if the intended buyers of this product have the highest marginal valuation for quality. The requirement for this result is that these buyers have a robust outside option as might be the case with replacement buyers who have an existing product. The introduction offers several examples of sequentially increasing quality that appear to be consistent with these findings.

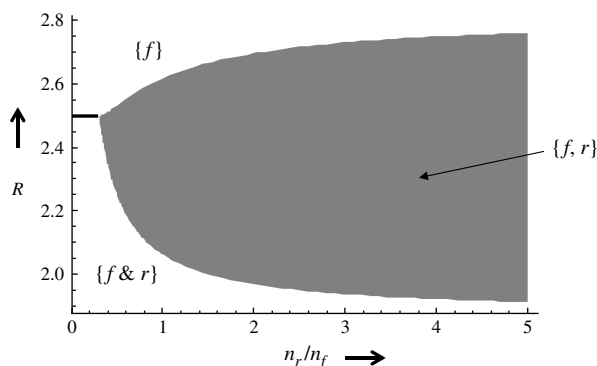
The managerial implications of our findings are as follows. If a firm is a later entrant to a product category, it is possible that many customers already own a product. In such a case, marketing managers may wish to tap the replacement buyer market in addition to selling to any first-time buyers. In general, to entice replacement buyers, managers may find it optimal to offer more product features as replacement buyers may value such features more. However, we find that it may be best to delay offering such a product until after first-time buyers are served. The rationale is that replacement buyers may expect lower prices because they already possess a well-functioning product. By delaying serving this segment, the seller can gain more profit from first-time buyers who are actively seeking the product. In this case, managers should recognize that they should necessarily go against the traditional strategy of introducing a more fully featured product before a less featured product.

As an extension to our work, one can look at the introductory strategy for a new-to-the-world product for which there are no replacement buyers at the time of the introduction. How would a seller who anticipates a segment of replacement buyers in the future from his initial product introduction strategically plan his product introduction sequence and the qualities to be offered? In effect, we would be looking at endogenizing the variable R in our model when analyzing such a problem. This could be a fruitful extension of our model in future research.

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Figure 2 Model with Commitment: Optimality Region for Strategy $\{f, r\}$ when $R \geq (\theta_r(\theta_r - \theta_f))/(2c)$



comments. The authors also thank an anonymous reviewer for suggesting additional examples of sequentially increasing quality introductions. This paper is based in part on the first author's dissertation submitted to Purdue University.

Appendix. Proof of Proposition 1

When $R \leq \theta_r(\theta_r - \theta_f)/(2c)$, we can show that the seller's profit in an $\{f, r\}$ equilibrium is lower than that in the $\{f \& r\}$ equilibrium. When $R \geq \theta_r(\theta_r - \theta_f)/(2c)$, we denote the seller's profit in the $\{f \& r\}$ equilibrium as $\pi_{\{f \& r\}, (iv)}$ when $R \leq \theta_r(\theta_r - \theta_f)/(2c) + (\theta_r - \theta_f)^2/(4cv) \equiv \alpha_2$ and $\pi_{\{f \& r\}, (v)}$ otherwise. Furthermore, we denote the $\{f, r\}$ equilibrium profit when $R \geq \theta_r(\theta_r - \theta_f)/(2c)$ by $\pi_{\{f, r\}, (iii)}$. We can show the following as $\delta_s \rightarrow 1$:

$$\pi_{\{f, r\}, (iii)} - \pi_{\{f \& r\}, (iv)} = -\delta_c n_f \left[R - \frac{\theta_r(\theta_r - \theta_f)}{2c} \right] + n_r \left[\frac{R}{\theta_r - \theta_f} - \frac{\theta_r}{2c} \right] c.$$

The above expression is positive when

$$R \geq \theta_r(\theta_r - \theta_f)/(2c) + \delta_c(\theta_r - \theta_f)^2/(4cv) \equiv \alpha_1.$$

Furthermore, we have the condition $R \leq \alpha_2$ for $\pi_{\{f \& r\}, (iv)}$. We can then show that $\alpha_2 \geq \alpha_1$ if and only if $\delta_c \leq \frac{1}{2}$. When $R \geq \alpha_2$, with the seller making $\pi_{\{f \& r\}, (v)}$ in the $\{f \& r\}$ equilibrium, we have the following as $\delta_s \rightarrow 1$:

$$\pi_{\{f, r\}, (iii)} - \pi_{\{f \& r\}, (v)} = (1 - \delta_c) n_f \left[R - \frac{\theta_r(\theta_r - \theta_f)}{2c} \right] - \frac{n_f^2 (\theta_r - \theta_f)^2}{n_r 4c}.$$

The above expression is positive when

$$R \geq \theta_r(\theta_r - \theta_f)/(2c) + (\theta_r - \theta_f)^2/(4cv(1 - \delta_c)) \equiv \alpha_3.$$

Furthermore, we can show that $\alpha_3 \geq \alpha_2$ if and only if $\delta_c \geq \frac{1}{2}$, yielding the condition $R \geq \alpha_3$ for $\delta_c \geq \frac{1}{2}$ as in part (b) of the proposition and the condition $R \geq \alpha_1$ as in part (a) of the proposition. Finally, we can show that $\pi_{\{f, r\}, (iii)}$ exceeds the profit in the $\{r, f\}$ equilibrium if $R \geq \alpha_1$ and $\delta_s \rightarrow 1$. Because $\alpha_3 \geq \alpha_1$, $\pi_{\{f, r\}, (iii)}$ exceeds the seller's profit in the $\{r, f\}$ equilibrium for both parts (a) and (b) of the proposition.

References

Akerlof GA (1970) The market for lemons: Qualitative uncertainty and the market mechanism. *Quart. J. Econom.* 84(3):488–500.

- Barnes N (2007) BMW's estate racer. *Sunday Express* (February 28) <http://www.express.co.uk/life-style/cars/400/BMW-s-estate-racer>.
- Bayus BL (1992) The dynamic pricing of next generation consumer durables. *Marketing Sci.* 11(3):251–265.
- Biyalogorsky E, Koenigsberg O (2010) High-low or low-high: Product-line introduction strategies. Working paper, Columbia University, New York.
- Gordon BR (2009) A dynamic model of consumer replacement cycles in the PC processor industry. *Marketing Sci.* 28(5):846–867.
- Gul F, Sonnenschein H, Wilson R (1986) Foundations of dynamic monopoly and the Coase conjecture. *J. Econom. Theory* 39(1):155–190.
- Hendel I, Lizzeri A (1999) Adverse selection in durable goods markets. *Amer. Econom. Rev.* 89(5):1097–1115.
- Kotler P, Keller KL (2006) *Marketing Management*, 12th ed. (Pearson Prentice-Hall, Upper Saddle River, NJ).
- Lassa T (2011) First drive: 2012 Mercedes-Benz C63 AMG Coupe. *Motor Trend* (May 20) http://www.motortrend.com/roadtests/coupes/1105_2012_mercedes_benz_c63_amg_coupe_drive/.
- Levinthal DA, Purohit D (1989) Durable goods and product obsolescence. *Marketing Sci.* 8(1):35–56.
- Moorthy KS (1984) Market segmentation, self-selection, and product line design. *Marketing Sci.* 2(4):288–307.
- Moorthy KS, Png IPL (1992) Market segmentation, cannibalization, and the timing of product introductions. *Management Sci.* 38(3):345–359.
- Mussa M, Rosen S (1978) Monopoly and product quality. *J. Econom. Theory* 18(2):310–317.
- Padmanabhan V, Rajiv S, Srinivasan K (1997) New products, upgrades, and new releases: A rational for sequential product introduction. *J. Marketing Res.* 34(4):456–472.
- Pfaff K (1993) Microwave ovens get bigger, easier to use. *HFD—The Weekly Home Furnishings Newspaper* (June 14) 90.
- Srinagesh P, Bradburd R (1989) Quality distortion by a discriminating monopolist. *Amer. Econom. Rev.* 79(1):96–105.
- Subramanian U, Raju JS, Zhang ZJ (2014) The strategic value of high-cost customers. *Management Sci.* 60(2):494–507.
- Tan C (2007) Merc to roll out new C-class models. *Straits Times* (January 20) 102.
- Tirole J (1988) *The Theory of Industrial Organization* (MIT Press, Cambridge, MA).
- Villas-Boas JM (1998) Product line design for a distribution channel. *Marketing Sci.* 17(2):156–169.
- Villas-Boas JM (2004) Price cycles in markets with customer recognition. *RAND J. Econom.* 35(3):486–501.
- Waldman M (1996) Durable goods pricing when quality matters. *J. Bus.* 69(4):489–510.
- Wathieu L (2004) Consumer habituation. *Management Sci.* 50(5):587–596.
- Xiong H, Chen Y-J (2014) Product line design with seller-induced learning. *Management Sci.* 60(3):784–795.